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IN THE

SUPREME COURT

OF THE

UNITED STATES.

OCTOBER TERM, 1931.

No. 43.

Bandini Petroleum Company, a corporation; Commodore Petroleum Company, a corporation; Wilshire Oil Company, Inc., a corporation; Wilshire Annex Oil Company, a corporation, and Ambassador Petroleum Company, a corporation,

Appellants,

vs.

The Superior Court of the State of California, in and for the County of Los Angeles, and Honorable William Hazlett, as One of the Judges Thereof,

Appellees.

BRIEF OF APPELLEES ON MERITS.

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Appellees.

BRIEF OF APPELLEES ON MERITS.

I.

THE OPINIONS OF THE COURTS BELOW AND THE CALIFORNIA STATUTE.

Bandini Petroleum Company v. Superior Court of the State of California, decided November 29th, 1930, Civil #7292, Second Appellate District, Division Two, State

NOTE: References hereafter made—"R" to the pages of the printed Record herein; "Supp." to Supplement to Brief of Appellees on Motion to Dismiss, Appeal or Affirm Judgment, herein, and "App'x." to the Appendix to this Brief filed under separate cover.

of California, not yet officially reported, but will appear in 109 Cal. App. Rep. ——. A copy of the opinion is printed in the Record, beginning with page 200, and again printed as an appendix to "Statement of Appellees as to Jurisdiction on Appeal" at pages 1 to 24. The opinion is unofficially reported in 63 Cal. App. Dec. 1175 and 293 Pac. 899.

People v. Associated Oil Co. et al., 211 Cal. 93, on application of Twin Bell Syndicate, *et al.*, for a Writ of Supersedeas from the Supreme Court of California, Dec. 3, 1930, not yet officially reported. A copy of the opinion is printed as Appendix B, beginning at page 19, in "Supplement to Brief of Appellees on Motion to Dismiss Appeal or Affirm Judgment" herein. The opinion is unofficially reported in 80 Cal. Dec. 607 and 294 Pac. 717.

People v. Associated Oil Co., et al., on the appeal of Twin Bell Syndicate and others from the preliminary injunction, decided March 26, 1931, not yet officially reported. The opinion is unofficially reported in 81 Cal. Dec. 279 and 296 Pac. 273. A copy of the opinion is printed as Appendix "C," beginning at page 45 of the Supplement above mentioned. *Ambassador Pet. Co. et al., v. Superior Court*, 208 Cal. 667 construing the statute in respect to parties and pleading.

California Gas Conservation Laws, being chapter 718, Statutes 1915, page 1410; as amended by chapter 759 Statutes of 1917, page 1598; as amended by chapter 536 statutes of 1919, page 1165; as amended by chapter 912 statutes of 1921, page 1724; as amended by chapter 535 statutes of 1929, page 925. Substantially all the pertinent provisions are contained in the statute of 1929. A copy of all the provisions mentioned by appellants on this appeal are printed as Appendix "A" to Supplement of Appellees' Brief, filed on motion beginning with page 3.

II.
JURISDICTION OF THIS COURT.

Technical jurisdiction exists in this court to review the decision of the California court appealed from on two questions, *first*, the power of the state to prohibit the waste of natural gas, and *second*, the sufficiency of the standard of unreasonable waste of natural gas to meet the requirements of "due process of law." If these two questions have been so explicitly decided by this court as to foreclose further argument, then this court should grant appellees' motion to dismiss the appeal or affirm the judgment below for lack of a sufficient Federal question, *Equitable Life Assurance Soc. v. Brown*, 187 U. S. 308, 314; *Bevins v. State of Iowa*, 282 U. S. 815. The motion of appellees to dismiss the appeal or affirm the judgment below has been separately briefed. The motion to dismiss will be submitted on the authorities contained in that brief and in the statement of appellees as to jurisdiction heretofore filed herein, without further citation of authorities. The alternative motion to affirm the judgment below is again urged as the proper disposition of this appeal, *Milheim v. Moffat Tunnel Imp. Dist.*, 262 U. S. 710. It is submitted that the whole case on the merits is covered by the opinion of this court in *Ohio Oil Co. v. Indiana*, 177 U. S. 190.

III.
STATEMENT OF THE CASE.

The statement of the case naturally divides itself into two parts: *first,* the nature of the original proceeding, its progress to this court, the position of the respective parties to the action pending in the trial court, the parties to the application for the Writ of Prohibition and the position of the parties on this appeal; and *second,* the nature of the property right subjected to regulation by the California statute, the impinging rights of neighboring owners over the same gas structure, the public interest in the regulation of production, and the appropriateness of the statutory regulations to the property right in natural gas and oil.

When the appellee equity court made its temporary injunctive order in the action against appellants, and other operators in the field to prevent the unreasonable waste of natural gas pending the trial on the merits, there were three remedies open to appellants if they considered themselves aggrieved:

> *First,* to apply to that court for a modification of the preliminary injunction, the power to make such modifications having been expressly reserved in the preliminary injunction;
>
> *Second,* to appeal the case to the Supreme Court of California and apply to that court for a Writ of Supersedeas requiring the appellee equity court to withhold enforcement of the preliminary injunction until the matter could be heard in the State Supreme Court; and
>
> *Third,* to challenge the jurisdiction of the appellee equity court on the ground that the statute is wholly unconstitutional.

The co-defendants of appellants, Twin Bell Syndicate, *et al.*, elected to appeal from the injunction and apply for a stay. Their application for a supersedeas was denied [*People v. Associated Oil Co.*, decided Dec. 3, 1930, Supp. 19, *supra*]. The preliminary injunction was sustained on appeal by a decision of the same court March 26, 1931, [*People v. Associated Oil Co., supra*, Supp. 45.] Appellants elected to challenge the jurisdiction of the equity court *to make any order of injunction* on the ground that the statute of the State of California necessarily infringed their fundamental rights under the Constitution of the United States. The attack by application for a Writ of Prohibition is an assertion that under any state of facts the equity court was without jurisdiction to make any injunction restraining the waste of natural gas. Under unusual circumstances this court has sent a cause back to the state court with directions to make its order conform to the opinion of this court; for an example see *Chicago, M. & St. P. R. Co. v. Minnesota*, 134 U. S. 418. If the Writ of Prohibition is denied by affirmation of the judgment below, these appellants have preserved to them their day in court both at the trial on the merits and by application to modify the preliminary injunction now stayed by supersedeas in this court and by appeal from any orders hereafter made. Under these circumstances it is the rule of this court that the complaining party must avail itself of the statutory remedies. (*Ex parte* Oklahoma, 220 U. S. 198.)

The *second* part of the statement of facts has to do with the peculiar nature of oil and gas commingled in strata under great pressure far beneath the surface of the earth, the manner of its production and utilization under the

conditions existing in the State of California, and the property right of each landowner to acquire title to the oil and gas in the earth by reducing them to possession at the surface.

III-A.

The Action in Equity, the Preliminary Injunction, the Application for a Writ of Prohibition, Its Denial and the Appeal.

The appellants here were the petitioners for the Writ of Prohibition in the California District Court of Appeal and the appellees here are the Judge and the court of general equity jurisdiction in which was and is pending the action to restrain the unreasonable waste of natural gas under the statutes of the State of California above mentioned. The District Court of Appeal of California, in its opinion denying appellants' application for a Writ of Prohibition, said:

> "This is an original prohibition proceeding. The petitioners seek to prevent the respondent court from enforcing a preliminary injunction and order modifying the same and also to check any further order or proceeding against them in an action pending in the respondent court entitled People of the State of California on relation of Fred G. Stevenot, Director of Natural Resources of the State of California v. Associated Oil Company, *et al.*, which action was brought for the purpose of enjoining all of the defendants therein named from unreasonably wasting natural gas from their wells in the Santa Fe Springs Oil Field. On March 19, 1930, after hearing the parties to the action, the court granted a temporary injunction limiting and defining the amount of gas which the defendants would be allowed to permit to escape into the

air from their wells in the field mentioned. On March 28, 1930, the court made another order somewhat relaxing the terms of the injunction *pendente lite*. It is asserted by petitioners that they have been irreparably injured and damaged by attempting to curtail the production of natural gas; that there is no market for a large part thereof, and that if they are to be allowed, as they claim it is their right, to employ the gas as a lifting power to raise the oil from below the surface, they must of necessity permit a portion thereof to escape into the air; that prior to the temporary injunction they were producing 19,554 barrels of oil per day, but that operating most efficiently under the amount of gas allowed to be used by the modified order they cannot possibly produce more than 10,211 barrels per day." [R. pp. 200-201.]

The preliminary injunction of the appellee Superior Court recited:

"The court having read the verified complaint and the affidavits in support of the relief prayed for in said complaint, and having read the verified answers of defendants on file herein and the affidavits filed on behalf of certain defendants, and having taken testimony, both oral and documentary, in open court and having heard the attorney for plaintiffs and the attorneys for the defendants appearing herein, the court finds that no sufficient cause has been shown why a preliminary injunction should not be issued as prayed for in said complaint, and as hereinafter provided, and the court having considered the law and the premises *finds* that there appears to be an unreasonable waste of natural gas in the Santa Fe Springs Oil Field; that to preserve the subject matter of the action to abide the decree of the court at the conclusion of the trial a preliminary injunction is

necessary at this time; that the evidence available to the court at this time shows that the unreasonable waste of natural gas in said field may be substantially reduced and that the equities of all parties may be fairly conserved by a preliminary injunction which will limit the waste of gas by restricting the production thereof to a quantity reasonably in excess of the present outlets for beneficial use above ground, require the extraction of gasoline from the gas produced in the field; that accordingly for the purpose of this order, the total gas outlets for all uses with a reasonable tolerance to take care of fluctuating demands and the necessary waste is taken at approximately two hundred eight-five million (285,000,000) cubic feet of gas each day, and the estimated potential production oil is taken at two hundred thirty-seven thousand five hundred seventy-six (237,576) (W. H.) barrels each day distributed among leases and other operating property units as shown in the schedule hereafter set out; and that sufficient cause has been shown for the extraordinary relief of a preliminary injunction pending the trial of the action on the merits, and the entry of a final judgment herein." [R. pp. 180-181.]

It was then provided that the defendants be enjoined until the further order of the court:

"1. From blowing, releasing or permitting any natural gas to escape into the air from any well or wells in the Santa Fe Springs Oil Field before the removal of the gasoline from such natural gas.

"2. From operating any well producing natural gas in the Santa Fe Springs Oil Field except while exercising a high degree of care in the selection and adjustments of appliances and in the use thereof for

the purpose of keeping each producing well in its 'optimum gas-oil ratio'—the term 'optimum gas-oil ratio' being defined as the smallest number of cubic feet of gas which can be produced with each barrel of oil from the same well at the same time.

"3. From producing more net formation gas on the average day of each seven (7) day period from any lease or other property unit than is set forth in the 'Allowed Gas Production' column in the schedule following." [R. pp. 181-182.]

The allowed gas production each average day was by the order of March 28, 1930, increased to 300,000,000 cubic feet. [R. 187 and 193.]

The unreasonable waste of natural gas by appellants declared unlawful by the statute and restrained by the preliminary injunction of the appellee superior court has two aspects.

Natural gas serves two great purposes, and, because it cannot be stored in quantities for future use above ground, in large measure it must be used as produced, or stored in natural reservoirs underground, or wasted. The use in producing the oil from the underground strata and the use in creating heat or other industrial energy above ground must be closely correlated in point of time. It will be reasonable to allow a greater quantity of gas to be wasted to the air where there is no waste of gas energy in producing oil, than where there is large waste of the gas energy in producing the oil.

III-B.

Appellants Were Contributing Between Forty and Sixty Per Cent of Their Production to the Prohibited Unreasonable Waste of Natural Gas by Releasing It to the Air Without Use of Its Heat and Energy Units.

There is no advantage in discussion until the terms to be used are agreed upon. "Waste" is a relative term with two extremes of meaning.

The California courts had to derive the legislative intent from the language used and facts within their judicial knowledge. This court has the advantage of the construction of the California courts in ascertaining the meaning to be attributed to the language of the California Legislature. The language used by the legislature excluded all but one dictionary meaning of the word "waste." When energy is converted into physical substance, or physical substance is converted into energy, there is always a margin of loss which may be theoretically measured by converting back. This loss is waste, but it is not unreasonable waste. There is also the definition of "waste" as "needless destruction or useless consumption." Under this definition of the term "waste," no characterizing adjective is necessary as it is already included in the definition. This is the "unrestrained license to waste" (177 U. S. 201) and to "protect from undue destruction" and the "extravagant or wasteful or disproportionate use of natural gas," (254 U. S. 314 aud 323). Had the California Legislature seen fit to prohibit all waste of gas after the removal of the gasoline therefrom, the courts would either have had to interpolate the word "unreasonable" before the word "waste" in order to give the statute an

operative meaning, or else to have declared the statute void as inoperative. This was the situation which confronted this court in construing the Sherman Anti-Trust Act in *Standard Oil Co. of N. J. v. United States,* 221 U. S. 1, 63-64, and subsequent cases. Referring to this "rule of reason" declared by this court in the last cited case, the Supreme Court of California, in *Ex parte Daniels,* 183 Cal. 636, 646, said:

> "It is scarcely to be assumed that this court would read into a statute by construction a provision which, had it been included therein at the time of its enactment, would have rendered the statute void and unconditional, because of the uncertainty involved in the use of the very term read into it by the court, namely 'reason'."

We find these two definitions of "waste" in the dictionaries in common use, one definition including within itself the characterizing adjective "needless," or "useless," or "unreasonable," and the other definition omitting the characterizing adjective. To make the meaning definite and certain, each user must indicate by appropriate language which of the dictionary meanings he intends. This the California Legislature did by the use of the word "unreasonable" to characterize the prohibited waste. Webster's New International Dictionary in defining "waste" says:

> "* * * a squandering; needless destruction; useless consumption or expenditure; loss without equivalent gain; * * *."

Here the definition itself includes the equivalent of the characterizing adjective "unreasonable." The dictionary definition continues:

"* * * gradual loss or decrease by use, wear or decay."

To exclude this definition as not intended, the user of the word "waste" must use a qualifying adjective. The legislature by the use of the characterizing adjective "unreasonable" made it clear that the waste prohibited and declared unlawful was the "loss without equivalent gain," and that waste in the sense of "gradual loss or decrease by use, wear or decay," or "loss by necessary destruction" was permitted.

This was no new problem for the Supreme Court of California, as there is a long line of well considered opinions in that court making the same distinction between "reasonable use" and "unreasonable waste" in the law of waters, to which we will refer when we discuss the analogies between the law of gas and oil and the law of waters. The matter is fully covered in the opinion of the District Court of Appeal rendered on the order appealed from.

On the hearing before the appellee court there was satisfactory evidence that during the year 1928 over seventy-seven billion (77,000,000,000) cubic feet of natural gas were wasted into the air from the sub-surface oil and gas zones in the State of California derived from the operation of oil wells. [Affidavit of Brown, R. p. 56; Supp. p. 20.] The natural gas so wasted into the air in 1928 was the energy equivalent of three million eight hundred fifty thousand (3,850,000) tons of good coal; twenty thousand (20,000) cubic feet of natural gas being taken as the equivalent of a ton of good coal. [Supp. pp. 84-85.] Many domestic consumers, industrial plants and

public buildings within the vicinity of Santa Fe Springs Oil Field depended upon a continuous supply of natural gas for heat and power and these uses, large at the time, were being extended. At the rate of discharge to the air existing at the time that the complaint was filed, in September, 1929, it was estimated by the witness Brown, oil and gas administrator for the Railroad Commission, that the Santa Fe Springs Oil Field would be depleted of natural gas within three years [R. pp. 56, 58]. This opinion is being confirmed. [*People v. Associated Oil Co., supra,* Supp. 48.] It was this evil of a blow to the air of an energy-producing substance which cannot be replaced in a commonwealth entirely without coal, that led the Legislature of California to recite that the facts of this waste constituted the necessity for the urgency measure as follows:

> "At the present time in the oil and gas producing fields within the State of California there is now being blown into the air and wasted daily on the average of approximately five million cubic feet of gas. New fields producing heavily of natural gas are being opened up which will tend to add to the amount of natural gas being blown into the air and wasted and lost." [Stats. 1929, p. 943, Supp. 18.]

By the blow to the air of five hundred million (500,000,000) cubic feet of gas per day [Complaint, Ex. "AA" following R. p. 36] there was a waste of energy in the Santa Fe Springs Oil Field, equivalent in energy to twenty-five thousand (25,000) tons of coal a day at the time the action was commenced. See opinion of the Supreme Court of California [Supp. p. 20]. For the month of July, 1929, in the Santa Fe Springs Oil Field the gas production was approximately eighteen billion seven hundred million (18,-

700,000,000) cubic feet, the use five billion four hundred million (5,400,000,000) feet, and the waste by blow to the air thirteen billion three hundred million (13,300,000,000) cubic feet [R. p. 58]. It is true that there was no market for this excess quantity of gas at the time, but, with a spread of production over three years instead of one, an adequate market was available. The opinion of the witness Brown that the gas supply from Santa Fe Springs would be depleted within three years was verified. The Supreme Court of California on the appeal from this very preliminary injunction by other parties, was able to say:

> "During the month of March, 1930, when the original injunctive order was issued, the daily average production of gas in the entire Santa Fe Springs Oil Field was five hundred sixty-five million seven hundred five (565,000,705) cubic feet per day. The injunctive order fixed the allowable daily production at three hundred thirty-four million (334,000,000) cubic feet per day. Taking into consideration and eliminating the amount of gas put to beneficial use, the court determined that any additional gas blown to the air in excess of one hundred million (100,000,000) cubic feet per day was 'unreasonable waste.' [Supp. 47.] In January of this year (1931) the daily average of production of gas in the entire field was reduced to one hundred seventy-seven million two hundred fifty thousand (177,250,000) cubic feet. This reduction was due wholly to the decrease in gas pressure in the various sands of the field. The production of oil in the whole field was necessarily reduced proportionately. *It therefore appears that the very thing that the state was endeavoring to prevent, namely, the improvident and wasteful use of natural gas, has been frustrated by unregulated operations in the*

field or by operations continued in spite of attempted regulation, with the result that the further recovery of oil in the discovered zones in this field has been unduly reduced by the heretofore wasteful process, and that such further recovery must depend on artificial gas repressuring or putting the wells on pumps." [Opinion California Supreme Court, Supp. 48.]

This preliminary injunction curtailed production in the field from five hundred sixty-five million seven hundred fifty thousand (565,750,000) cubic feet of gas each day to three hundred thirty-four million (334,000,000) cubic feet each average day. See Brown affidavit [R. 58] and injunction [R. 187-193]. The injunction curtailed appellants gas production from fifty-seven million one hundred twenty thousand (57,120,000) cubic feet a day to twenty-eight million one hundred sixty thousand (28,160,000) cubic feet a day. The peak use remaining constant at 220,000,000 cubic feet, this order would reduce the blow to air from 335,000,000 cubic feet to 115,000,000 cubic feet, amounting to a reduction in blow of 220,000,000 cubic feet each average day below that existing without the order. See Charts affidavit, Brown. [R. 60-61.]

The appellants were admittedly blowing to the air between 40% and 60% of their production, amounting to twenty-two million eight hundred forty-eight thousand (22,848,000) cubic feet a day [R. 116 and Appellants' Brief in Opposition to Motion to Dismiss, Appeal p. 14.] This blow of natural gas to the air by appellants, taken at 40% [R. p. 116], was the equivalent of one thousand one hundred forty-four (1,144) tons of good coal a day. [Supp. p. 85.] It is the basic contention of appellants that there was no market or use for the excess gas being

produced, from which it follows that any decrease in the production of natural gas in this field resulted in an equivalent reduction of the gas blown to the air. This cut in gas production required by the order if observed would have resulted in a cut of approximately fifty (50%) per centum in the oil production of appellants. This reduction was the general average throughout the field. The order also operated to diminish the underground waste of natural gas. Each operator being allowed to produce a limited quantity of gas in its own interest would utilize its allowance of gas to produce the largest quantity of oil. This would, and with few exceptions did, result in each operator keeping on production its lowest "gas-oil ratio" wells and closing in its wasteful "gassers." That these appellants could comply with the order of the equity court is shown by their own report. [R. p. 11.] Bandini Petroleum Company by beaming back all the wells or taking one more well in the deep sands off production (as shown by this report) could have complied with the order. The other appellants were in substantial compliance, *but they desired to reopen their wells and again increase production.* [R. pp. 11 and 16.]

When in 1912 the natural gas industry commenced to play a leading part in the production of heat and mechanical energy for use throughout the country, the Department of the Interior published a report recognizing that "enormous quantities are wasted annually, quantities too great even to be estimated, and it is with the greatest difficulty that interest can be aroused to the importance of conserving this valuable fuel and preventing the exhaustion of the fields." The continuing effort had its effect. In the

Appendix filed with this Brief under separate cover we quote from some of the reports of which the California Supreme Court took judicial notice. The immediate occasion for action by the California Legislature grew out of Report III of the Federal Oil Conservation Board to the President of the United States, under date of February 25, 1929, containing the report of its committee of nine of date January 28, 1928. [See p. 63 of the Supp. to Brief of Appellees on Motion to Dismiss Appeal or Affirm Judgment.] This report brought home to the California Legislature that the remedy for the waste of natural gas taking place in a state entirely without coal was within its police power, and, if permitted to continue without legislative action, the resulting damage to the state would be chargeable to the legislature as well as to the uneconomic activities of the producing companies. The duty seemed clear, and the undisputed finding that five hundred million (500,000,000) cubic feet of natural gas a day was being blown to the air unused and that this waste was increasing was recited to bring the act within the emergency powers of the legislature.

The increasing demand for natural gas in domestic use required that the supply be conserved. The reports for the year 1929 showed that California had the largest number, 1,239,000, domestic users of natural gas in any state. (*Gas,* Natural, International Year Book, 1930, p. 297.) For progressive increase in use of natural gas for domestic purposes see Supp. pp. 93, 95, 97.

III-C.

Unreasonable Waste of Natural Gas in the Production of Oil.

At 3450, at 4100, at 4900, at 5700, at 6200, at 7200 and at 8000 feet, respectively, below the land surface of Santa Fe Springs Oil Field, there is a zone of sand strata filled with oil and gas under high pressure [Complaint at R. 24; affidavit of Bush, state oil and gas supervisor, at R. 42; affidavit of Huguenin at R. 47]. The land surface within the oil field is divided into not less than 1145 parcels owned of record by more than 110 owners, many of the parcels being rectangles, less than 75 feet by 100 feet, and more than 41 operators have drilled from the surface into the producing zones mentioned [Complaint R. p. 25, affidavit of Huguenin at R. p. 47]. The pressure in each oil and gas zone was created and is maintained by the weight of edgewater in the zone compressing the gas content. A production zone is made up of the oil and gas producing strata between water bearing strata required to be cemented off at the well. [R. 42.] These zones are arched or domed and the oil with the gas is caught and held in the convex curve or anticline of the dome. [R. 42.] Over eighty-five (85%) per cent of the gas confined in the oil-bearing sand is methane and ethane, which do not liquify at any temperatures and pressures occurring in the zones. (Miller report, 1928, pp. 27 and 191.) Some portion of the lighter oil may vaporize, but it does not change into gas. The gas in the oil sands is greatly compressed and closely associated with globules of oil between the particles of sand throughout the zone. There is a definite quantity of oil and a definite quantity of gas in the zone before it is opened by a well. This original fixed

quantity of gas in cubic feet computed to atmospheric pressure divided by this original fixed quantity of oil in barrels of forty-two liquid gallons each gives the original or formation "gas-oil ratio." If a more accurate "energy gas-oil ratio" is desired the gases which liquefy at the temperatures and pressure must be subtracted from the total gas, and the barrelage of oil increased to the total of liquid raised by the compressed methane and ethane gases. There is a general uniformity of pressure and homogeneity of content throughout the sands of each zone. Where the vertical depth of the sands within the zone is great there will be some variation in the porosity and permiability of the sand, and the oil will be heavier at the bottom, gradually becoming lighter until in some places a "gas cap" will be found at the top of the zone. When a well is opened into a zone of oil bearing strata the pressure of the expanding gas forces the mingled fluid of oil and gas toward and out of the well, creating an inverted cone of lowered pressure about the well. As the fluid comes from the well its former place in the sands is filled by oil and gas pressing in from ever greater distances to equalize pressure in this cone at the well. At the same time, but more slowly than the gas, the edgewater advances to restore the zone pressure and in compensating measure decrease the zone space by contracting at the outer boundaries the cubical content of the oil and gas space in the zone. If the fluid oil and gas comes out of the well at or near the original formation gas-oil ratio a large part of the oil in the zone will be recovered. If the well is opened into or near the "gas cap" at the top of the dome the proportion of gas to oil that comes out is usually large and we have a high production gas-oil ratio with a low re-

covery of oil. This gas-oil ratio usually can be decreased by lowering the intake of the flow string deeper into the sands where the heavier oil is found, and also by pressing the gas back through the depleted production cone at the well. This is illustrated by figures 33 and 34 from Bureau of Mines, Pulletin 323, pp. 84 and 86. [See App'x. pp. 43-47, and affidavit of Gaylord, R. 51-52.] The limit of beneficial results from this back pressure is obtained just before the original zone pressure is reached. The sand in the zone offers a greater impediment to the flow of oil toward the well than it does to the flow of gas, and the oil deprived of its solution gas becomes more viscous. This in turn results in the gas leaving the oil with which it is associated and "slipping up the structure" toward the intake of the well, carrying with it progressively smaller and smaller quantities of oil as the distance of the source of supply from the well becomes greater and greater. As the sands in the immediate vicinity of the well become depleted of their oil and gas and the gas comes to the well from greater distances bringing an ever decreasing proportion of oil, we have progressively a higher and higher production "gas-oil ratio." To some extent this progress will be delayed by holding back the production of the well by the gas back pressure above mentioned. Unless the sands are very open and the edgewater drive unusually heavy after the flush production even with the best adjusted back pressure there is a steadily increasing gas-oil ratio until the well, if continued on production, becomes a "gasser." If taken off production it may be restored when the water drive has replenished the depression cone with oil. The oil deprived of its gas becomes more viscous, adheres to the sand in larger proportions, the

edgewater "fingers" in, cutting off bodies of oil sand from contact with the main body, all of which contribute in reducing the recoverable oil. [See Miller, "Function of Natural Gas in Production of Oil," quoted in App'x. filed with this Brief beginning at p. 12.]

For every one thousand (1000) cubic feet of gas produced with a barrel of oil above the first thousand (1000) cubic feet safely above the formation gas-oil ratio, [Miller Gas Lift Method, California Practice, Bureau of Mines, Bulletin 323, App'x. pp. 37-38] from a zone too deep to be reached by pumps, there is left in the ground a barrel of oil, and the ultimate recovery of oil is reduced accordingly. As production continues the hydraulic head of edgewater will engulf the flank wells and drive the oil up the structure toward the top of the dome. Until the edgewater advances through the depleted sands, makes up its loss of head due to absorption and begins its drive on the oil production. Every known oil and gas field in California (not on pump) produces by gas pressure and that pressure is maintained by a head of edgewater. Where the field is not over drilled and adequate back pressure is maintained in the fullness of time additional oil will be brought to the wells under a drive of edgewater toward the well. (There is one small well in Santa Barbara County which may produce by contraction of the geological fold.) If the high gas-oil ratio wells at the dome are closed in before they become "gassers" and restored to production on "gas lift" or placed on pump, the highest ultimate recovery of oil will be had. As the water advances beyond the flank wells driving the fluid oil and gas up the structure, the wells on the top of the dome can be

restored to production, provided the gas has been held back in the oil. In this manner the production rights in all parts of the field will be equitably adjusted. In zones near the land surface the head of edgewater will drive some of the oil deprived of its gas within reach of the pumps, but the increased viscosity will decrease the recoverable oil. Where the dome of the oil and gas zone is far below the land surface the pumps will not be able to reach the oil at the top of the dome whither it has been driven by the edgewater head. Deprived of its gas, this oil cannot be produced, is lost and wasted. [R. 139.] This was the situation in the various producing zones in the Santa Fe Springs Oil Field. Pressure of formation natural gas is the only available energy which will produce the oil at the surface from deep structures such as these appellants were and are producing from. From zones near the land surface the oil deprived of its gas may be produced by pumps, but gas pressure alone will produce the oil from the deep zones. The proportion of gas in solution varies with the pressure and the pressure with the depth. The pressure is approximately the weight of, allowing 42 pounds to 100 feet of a column of water, at 6500 feet the pressure would be about 3000 pounds [Supp. pp. 83-84]. The gas in solution is approximately 0.2 cu. ft. to each pound of pressure and at a depth of 6500 ft. would be about 600 cubic feet to a barrel of oil. [Miller Tech. 323, p. 22, App'x. p. 39.]

Every increase in production gas-oil ratio above the formation gas-oil ratio decreases proportionately the recovery of oil. This is the underground waste of gas complained of. Where gas which has not performed its duty in producing oil is released to the air there is a double waste.

III-D.

Judicial Notice. Evidence Quoted. The Situation Illustrated.

The pleadings and motion affidavits of plaintiff were incorporated as a part of appellants' papers on their application for the Writ of Prohibition. [R. p. 2.]

The affidavits submitted fully sustain the recitals of the appellee court. The witness Huguenin testified:

> "That attached to the complaint is map marked Exhibit "A" hereby made a part of this affidavit and on said Exhibit "A" is located each of said parcels and each of said wells. That in the sands of the Lower Buckbee Zone, the Upper O'Connell Zone, the Lower McConnell Zone, the Upper Clark Zone, the Lower or Second Clark Zone and the Hathaway or Third Clark Zone are large quantities of natural gas under high pressure, which gas causes the oil and gas to discharge with great force at the surface through and out of the wells from the sands in the said zone.
>
> That there is now being wasted, blown, released and allowed to escape into the air by the acts, omissions, sufferance or insistence of the defendants an aggregate of more than four hundred million cubic feet of natural gas (after the removal of the gasoline therefrom) each day of twenty-four hours from the said subsurface zones of the Santa Fe Springs Oil Field herein referred to, which discharge of natural gas has continued for more than thirty days next last past. . . . .
>
> That the gas so being blow, released and allowed to escape into the atmosphere can be saved and conserved by defendant operators in said Santa Fe Springs Oil Field by confining said gas in the zones of said field.

That a cubic foot of gas as referred to in this affidavit is measured at a temperature of 60°F. and a pressure of 14.733 pounds per square inch, and a barrel of oil as referred to herein contains 42 liquid gallons.

That in addition to the value of the gas unreasonably wasted from said wells, as aforesaid, the recoverable supply of oil and gas in the zones of said Santa Fe Springs Oil Field is greatly diminished by permitting said wells to flow freely without sufficient "back pressure" at the surface. That said back pressure is necessary throughout each of the said zones in the said Santa Fe Springs Oil Field in order to retard the rapid encroachment of edgewater into each said zone, and the consequent displacement of the gas therein contained." [Affidavit of Huguenin, R. pp. 47-48.]

The witness Gaylord testified:

"The flow of oil through an oil zone well is caused chiefly by natural gas which seeks the well as a point of diminishing pressure. The ultimate recovery of oil from oil sand depends largely upon the quantity of gas available in the sand for carrying oil to the wells. The ratio of the original quantity of gas to the oil in different oil and gas sands varies greatly, but because of the important part played by natural gas in the recovery of oil, the conservation of natural gas is of the utmost importance to every oil operator and to the community dependent upon a continued supply of oil or gas or both.

In two adjacent wells producing from the same zone the quantity of gas produced per barrel is to a large extent a measure of the relative efficiency in oil recovery of these two wells. If one of these wells produces a barrel of oil with five hundred (500)

cubic feet of natural gas and the [fol. 81] other a barrel of oil with one thousand (1000) cubic feet of gas, the first well is believed to be much more efficient than the second well, and while it cannot be assumed in the light of present information that a well will ultimately produce twice as much oil if it can be controlled to produce at the rate of five hundred (500) cubic feet instead of one thousand (1000) cubic feet of gas per barrel of oil, nevertheless, it can be stated that the ultimate production of a well will be greatly increased if the quantity of gas discharged from the well can be delayed." . . .

"That each and every withdrawal of more gas than is dissolved in the oil by one of such operators through a well entering the sand of any one of said zones reduces the supply available to each other such operator of a well into said zone and increases the difficulty of each operator in obtaining oil and gas through a well drilled into the said zone from the surface of the land owned by him or through which he has a right to produce oil and gas. That each and every such withdrawal of gas does and will reduce the gas pressure in the said zone sand throughout the whole of said zone as it extends in, under and through said Santa Fe Springs Field." [Affidavit of E. G. Gaylord, R. pp. 50, 52.]

The affidavit of Bush is to the same effect. [R. 43.]

The trend of development and application of methods of increasing recovery are detailed in the report of the American Petroleum Institute Committee of Eleven, which classifies the application and developments as follows:

"1. To conserve as much as is possible in the formation, *i. e.*, to keep the ratio of gas to oil produced as low as possible.

"2. To return dry gas from compression and absorption plants back to the oil-gas producing stratum for the purpose of conservation and increased production.

"3. To locate wells with respect to structure so that the gas-oil ratio may be kept as low as possible." (Report Conservation Committee A. P. I., Bulletin 3, Jan. 12, 1928, as quoted in "Increasing the Recovery of Petroleum", Osgood, Vol. 2, pp. 818-19.)

From the article entitled, "Gas, Natural," Americana volume 12, p. 302, *et seq.*, edition, appearing in Supplement, at page 83, we quote the following:

"In composition, various samples of natural gas differ very considerably, but its principal component is methane, or marsh gas (CH_4), ranging from 81 per cent for Pennsylvania and West Virginia gas to 98 per cent in some of the gas produced in Oklahoma. * * *

"Gas, because of its natural qualities, has a tendency to make its way for long distances wherever there are hollows in which the pressure is less than its own, and only collects in considerable quantities where there is an impermeable stratum of clay or rock to prevent further movement. In these hollows it accumulates under varying pressures depending upon their depth below the surface, the pressure having a close relation to the weight per square inch of a column of water of the same height; from which it is argued that the pressure found in natural gas reservoirs is derived from water forcing the gas out of a lower level. * * *

"The standard used in measuring fuel values is called the British thermal unit, written B. T. U., and is the amount of heat necessary to raise the temperature of one pound of pure water 1° F. at or near 39° F., which is the temperature of the maximum density of water. As tested by this standard various samples of natural gas showed heat values ranging from 740 to 1,312 B. T. U. per cubic foot. * * *

"About 20,000 cubic feet of natural gas will equal one ton of good bituminous or anthracite coal. * * *

"The heat value stored in natural gas is greater than that caused by any artificial combination of carbon and hydrogen, and it is a perfect fuel, as it issues from its original rock-sealed reservoirs. No preparation is necessary for its combustion, and no residue is left. It is not affected by ordinary temperature and it is easily distributed by pipes to points of consumption. It is a most economical source of light and power, and an ideal household fuel."

The earliest reports to give attention to the underground waste of gas in the production of oil were by J. O. Lewis and W. F. McMurray in Tech. Paper 130, Bureau of Mines, 1916, pages 5-9; and by J. O. Lewis in Bulletin 148, Petroleum Technology 37, Bureau of Mines, 1917, pages 117-120. In Bulletin 148 above cited the author says:

"There is a definite and limited amount of natural energy associated with the oil in each field, and largely upon how effectively that energy is utilized to expel the oil from the sand will depend what proportion of the oil in the sand may be recovered, for evidently *the exhaustion of a well is caused more by the exhaustion of the natural expulsive forces than by the depletion of the supply of oil.* If the natural gas associated with the oil is permitted to escape unrestricted and without performing the greatest amount of work possible, the producer is lessening the quantity of oil that may be obtained by natural means. Every foot of gas produced wastefully may be considered to represent a quantity of oil that should have been brought to the surface by using the gas effectively. It appears logical to gage the efficiency of production methods by the relative volumes of gas produced with the oil at the same well. If, for example, a change in method reduced the volume of gas produced with each barrel of oil from 2,000 to 1,000 cubic feet, much more oil could be

recovered eventually, even though the actual daily production of oil were reduced a little temporarily.

"Few have realized to what a degree *recovery is dependent upon the efficiency in utilizing the natural gas found associated with the oil*, nor that it is possible to regulate, at least partly, the conditions of expulsion."

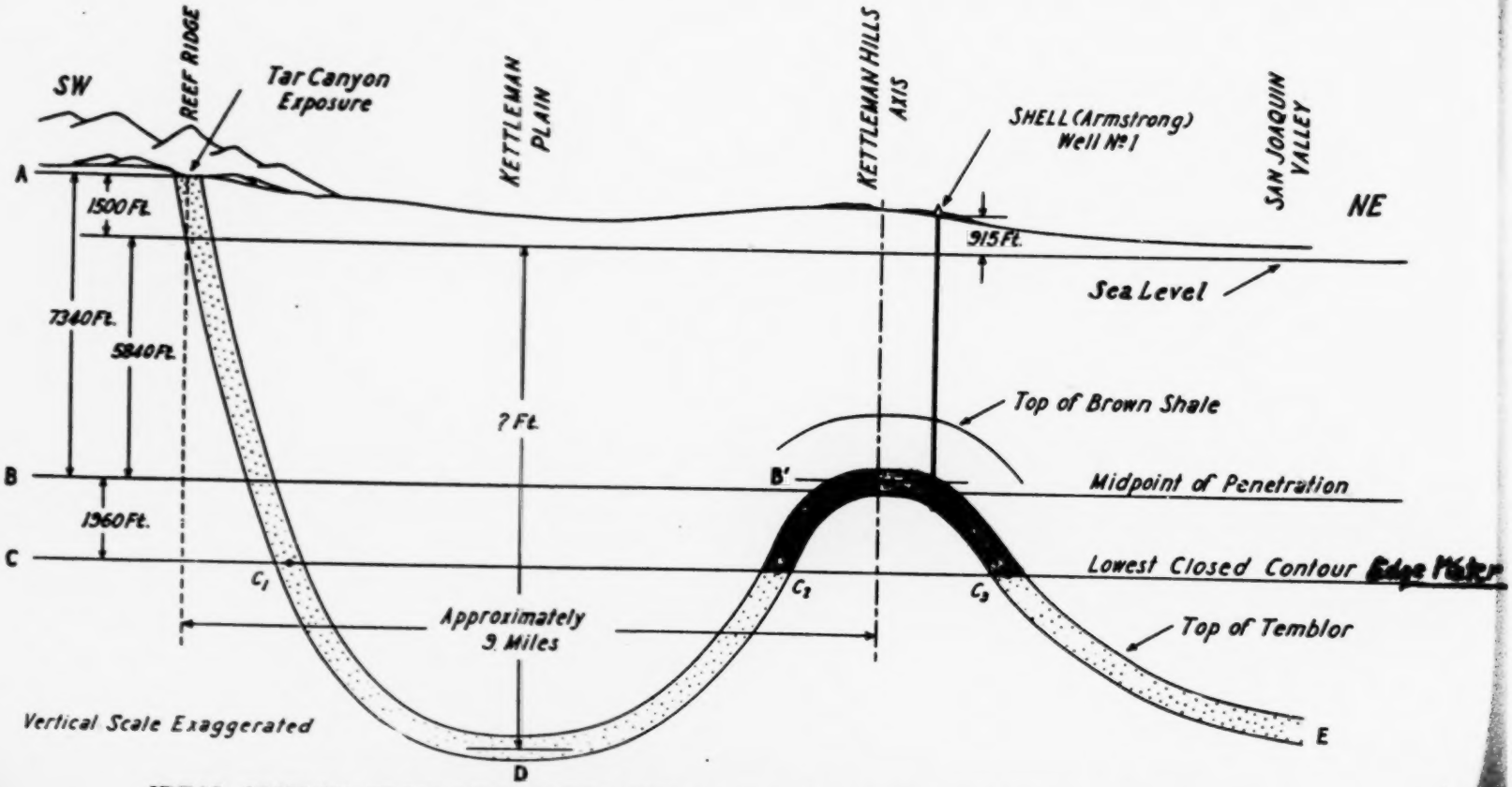
The witness Stanley C. Herold testified before the appellee court as follows:

"(9) The compressed gas within each pool is the source of energy which delivers the oil to the bottom of the well, from all directions radially outward, for a short period of time known as the period of flush production.

"(10) Water under hydrostatic head, transmitting its pressure through edgewater surrounding the pools, is the source of energy throughout the remaining life of the wells on settled production."

[Quoted from Supplement to Appellants' Brief in Opposition to Motion to Dismiss, p. 14.]

This witness, Stanley C. Herold, whose testimony is so quoted by appellants, has recently written an authoritative treatise published by the Stanford University Press under the title, "Analytical Principles of the Production of Oil, Gas and Water from Wells," containing a summary by Mr. Ernest K. Parks. This summary the author incorporates at page 589 as stating the value of his work to the industry without a detailed study of the entire book. We make this summary a part of our argument, and print it in the Appendix to this Brief at page 59. In connection with this summary, for purposes of illustrating control under hydraulic head, we append a print of, an "Ideal Section from Reef Ridge Through the Kettleman Hills Anticline," adapted from an article by Roy G. Mead (one of appellants' witnesses) in Oil Bulletin, July, 1931, page 509. Explaining the illustration, Mr. Mead says:



IDEAL SECTION FROM REEF RIDGE THROUGH THE KETTLEMAN HILLS ANTICLINE

Adapted from article by Roy G. Mead in Oil Bulletin, July, 1931, Page 509

"The productive limit of the temblor sand is tentatively placed at the contour 7800 feet below sea level, which is 9300 feet below the outcrop of the temblor sands in Tar Canyon below Reef Ridge. If the 7800-foot contour marks the present position of the edgewater surrounding the oil and gas reservoir, the pressure at that contour is equal to the hydrostatic head due to the difference in elevation of the outcrop below Reef Ridge and the 7800-foot contour.

"The force due to the hydrostatic head has compressed the gas, producing a closed-in pressure of 3300 pounds per square inch in the formation at the bottom of the wells. If the sands are replenished with water entering the formation where the streams cross the temblor sands below Reef Ridge, the pressure at the wells should show no decline after the original expansion of the gas in the vicinity of the well. An ideal section from Reef Ridge through the Kettleman Hills anticline is shown in an accompanying diagram."

For an early discussion of the hydrostatic head which produces the oil and gas in the dolomited upper 100 feet of Indiana Limestone, and the porosity and permeability of this upper portion of the strata see report by Edward Orton in 1886-7 entitled, "The Trenton Limestone as a Source of Petroleum and Natural Gas in Ohio and Indiana," eighth annual report United States Geological Survey 1887-8, p. 475 and following. A report of investigation several years later was published in the report of the Smithsonian Institute to the Congress and is quoted in the Appendix filed with this Brief at page 51. A report by Arthur John Phinney on "The Natural Gas

Field of Indiana" in 1889-90 was published in the eleventh annual report of the United States Geological Survey of 1890-91 (pp. 579-605), in which he locates on a map of Indiana the portions of the field in which oil was being produced. In this report made two years before the Indiana statute was enacted in 1893 and nine years before this court decided the Ohio Oil case, he said:

> "While the structural conditions and altitude of the Trenton limestone are the main factors in determining the gas supply, there is a third factor of equal importance, viz., its texture. It has already been stated that the Trenton limestone is not throughout its whole extent or thickness a gas-producing rock, the productive portion being confined to the upper 50 feet within which the porous gas-bearing stratum varies from 1 to 20 feet in thickness. The porous stratum is usually overlain by a hard non-porous cap rock varying in thickness from 1 to 15 feet. In this porous stratum, which is dolomitic so far as known, the Trenton yields gas abundantly. But it is only where such conditions exist, combined with favorable structural conditions that the potency of this factor is evident. The relation between rock texture and flow is proved by the behaviour of wells; for the flow, feeble at first, gradually increases as the drill sinks into the porous stratum and culminates when the base of the porous stratum is reached. It is only in rare instances where the gas comes with a gush, as though a cavity or open space had been found. There is no foundation for the popular belief that the gas of the Trenton is accumulated in caverns or open fissures formed by fracture of the strata during upheavals, for the drillers have failed to find caverns, fissures, or other vacant spaces of any considerable dimensions in the Trenton. There can be no reasonable doubt that the gas is simply accumulated under pressure within the minute pores and interstices of the coarse-grained dolomite." (Phinney, p. 657.)

The open character of the California oil sands has been tested by water flow. Lewis wrote in 1917:

> "In view of the many variable factors influencing the movement of the water, it is not surprising that the rates at which the water travels and the area affected by one well vary widely in the different oil fields of this country. It must not be inferred that the slow movements of water shown by experience in the Bradford field are usual, for they are evidently slow and restricted even for the eastern fields. In contrast the water has been known to travel through the sands in California fields distances in days that it would take years to advance in the Bradford field, and one well has been known to seriously injure large areas." (Pet. Tech. 37, p. 99. Bulletin 148, Bureau of Mines.)

The importance of gas in oil production and the various factors to be taken into consideration in determining whether a reasonable use of the gas is made in production is discussed at length in the report of H. C. Miller, senior petroleum engineer, U. S. Bureau of Mines, published by the Department of Commerce under the title "Function of Natural Gas in the Production of Oil." This report was judicially noticed by the Supreme Court of California [*People v. Associated Oil Co.*, Supp. p. 34]. Quotations from this report are printed in the Appendix to this Brief, covering the following:

> In undisturbed reservoirs the pressure corresponds with that of a column of water of a height equal to the depth below the surface and the pressure is hydrostatic. [p. 20, App'x. p. 14.]

> Where the oil pool in the reservoir is not backed by water in hydrostatic connection with it, the gas

associated with or dissolved in the oil is the only productive energy. [p. 21, App'x. p. 15.]

Methane (which constitutes about eighty per cent of the gas in California oil structures) cannot be liquefied by any pressure in the well. [pp. 26-28, App'x. pp. 19-20.]

At a pressure of 1800 pounds, a reservoir pressure corresponding to a depth of 4100 feet, sufficient gas may dissolve in the oil to reduce the viscosity until it equals that of kerosene. (p. 41, p. 202, App'x. pp. 26-28.]

Concluding this discussion, Miller says:

"It is evident that the most efficient method of gas utilization is one where the gas moves with the oil so that the gas-oil ratio approaches as nearly as possible the amount of gas dissolved in the oil at the existing reservoir pressures." [p. 47, App'x. p. 27 *et seq.*

The plat inserted showing the Bandini lease of appellants is a reprint of a portion of the map Exhibit "A" [R. pp. 36-37], and the circles shown are centered at the well locations of appellants contributing to the blow of gas to the air. The circles are drawn to a scale radius of 235 feet, giving an enclosed area of four acres about the well locations. Counsel for appellants insist that the courts take judicial notice that the oil drainage of the well is approximately four acres (Appellants' Brief on Motion, p. 39; Appellants' Brief on Merits, p. 60). The answer of defendant appellants admits that a well drains four or five acres [R. 93].

The drainage area of four acres around a well for the production of oil is accurate enough for all ordinary purposes before the hydraulic head of edgewater begins to act in driving oil from greater distance into the area of the depleted cone about the well. It is recognized that the gas comes from very much greater distances than the oil, which is referred to by the geologists and petroleum engineers as "slipping up the structure." The greater distance from which the gas comes, depends primarily on pressure in and permeability of the sands. Appellants' wells distant from the crest of the dome, one group being situated easterly, and the other group westerly along the major axis of the structure naturally produced at a lower gas-oil ratio than those on top of the structure. The top of the dome is located at the intersection of Butler Road and Anaheim-Telegraph Road [R. 136, and see map exhibit for location relative to appellants' wells, R. pp. 36-37]. The sketch showing ideal cross sections along the lines on the map at the end of the Appendix is compiled from the record. The flank wells mentioned in the schedule attached to the complaint and to the affidavit of the witness Huegenin situated on the structure are taken to locate the boundaries of the oil producing sand in each structure, and the distance to the Whittier fault is taken from the geological survey reports. (Geology and Oil Region of Puente Hills Region by Walter English, U. S. G. S. Bulletin 768.)

Attention is called to the fact that four of appellants' producing leaseholds are less than an acre in area, so that if the oil drainage is from an area of four acres each of the wells on these leases are drawing by far the larger part of their oil and gas production from the lands of owners other than appellants. When a well is driven to a depth of six thousand feet a drift from the perpendicular of three (3%) per cent is normal and the well is considered a straight hole. These wells of appellants are producing from a depth below six thousand feet. If appellants' wells are normally "straight holes" they may still have their intakes in the producing sands entirely outside of the conical segment of the earth determined by a line projected from the center of the earth rotating through the surface boundaries of the land parcel. We reproduce in the Appendix at page 44 a sketch of an oil well on "gas lift." This may be modified by introducing the repressured gas through the tubing and producing through the casing, or by closing the casing and using a smaller tubing through the tubing to a greater depth into the oil sand. Each will produce better results according to the pressure, permeability and degree of depletion of the sands. A similar sketch is reproduced from Bureau of Mines Bulletin to show a well on production under natural gas pressure taking wet gas from the casing and oil from the tubing in *Reynolds v. McMan Oil and Gas Co.,* Tex. 11 S. W. 787.

Since the year 1928 a drift of three per cent from the perpendicular has been found to be the average. We have included in the Appendix filed with this Brief an article by Mr. Paul J. Howard, inspector of the division of oil and gas, contained in the fourteenth annual report of the State Oil and Gas Supervisor of the issue of June, 1929, with figures and tables. His report was based upon an examination of 255 wells drilled during the years 1925 to 1928, inclusive, and 183 wells drilled after 1928. In an article entitled "Making Crooked Holes Useful," Mr. R. P. McLaughlin, Petroleum Engineer and Geologist, experienced in the matters of surveying oil wells, outlines how wells may be diverted from the perpendicular to reach sands as much as three thousand feet away from where the well would bottom if drilled vertically. He suggests that an intentional drift from the vertical will enable the operator to reach oil sands beneath the ocean by wells drilled on the shore, and avoid faults which break the continuity of the producing zones. When, however, we find as many as ten wells drilled upon a single surface acre with four wells producing from the same O'Connell Zone [Getty S. F. Exhibit "A", R. 36, and Exhibit "C," R. 164], we realize to what use this method of drilling may be put. Mr. McLaughlin confirms the report of Mr. Howard, saying:

> "Almost every careful operator now aims to drill a straight hole. After a careful examination of many records, the writer deems it fairly safe to state that it is impossible to drill a well absolutely straight and

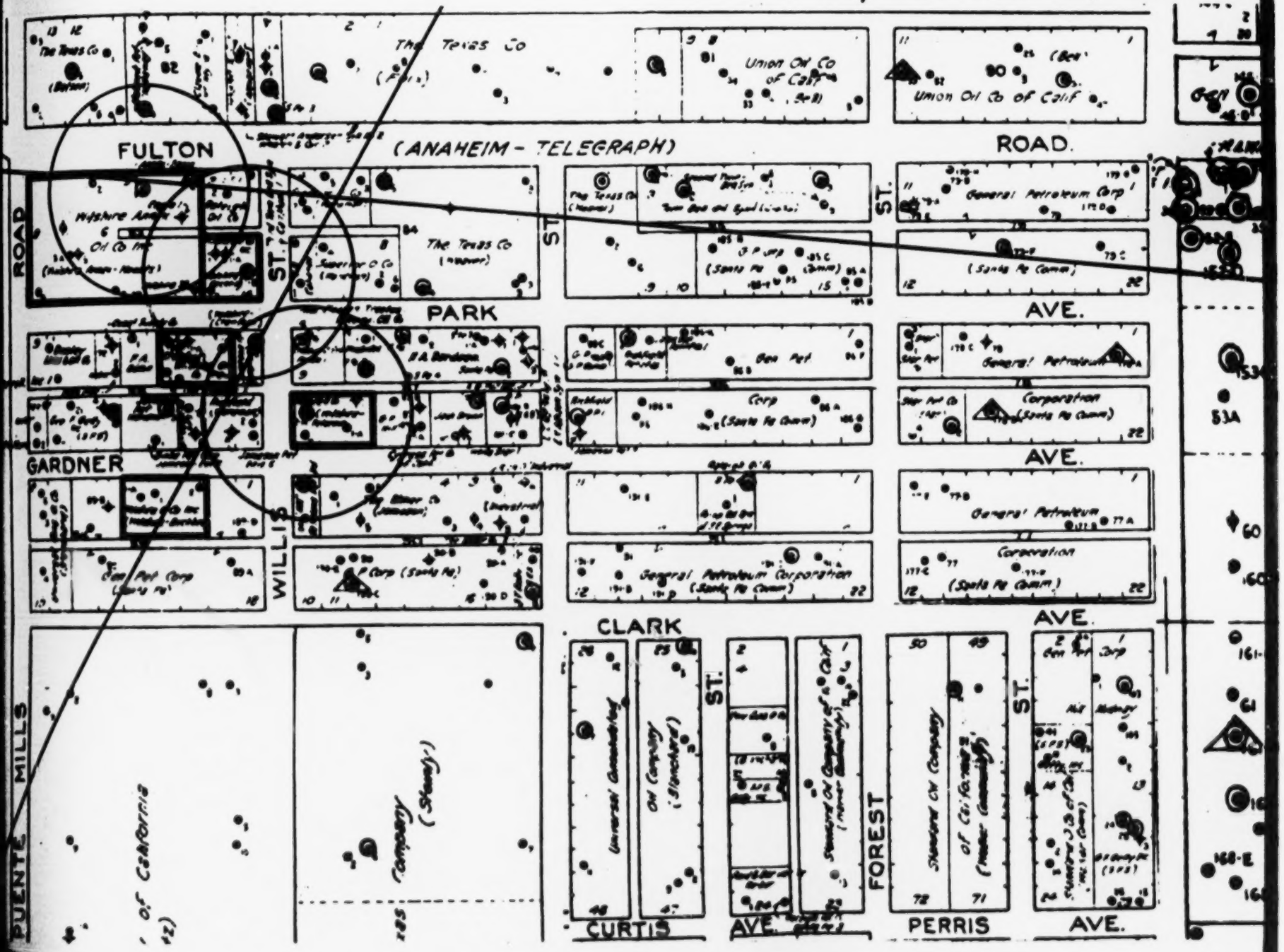
vertical under the practical conditions which limit the profitable expenditure of both time and money. A well which does not deviate more than three degrees from vertical is, under present conditions, considered a straight hole, although it has many slight bends and turns. Such a well at a depth of six thousand feet may drift horizontally as much as three hundred feet. Under these conditions the well is so far from straight that pumping operations will always labor under a certain handicap. Furthermore, the bottom of the hole is likely to be a full location away from the position chosen on the ground surface and two wells may be so close together at the bottom that they are performing the duty of only a single well." (Oil Bulletin, August 1930, p. 826.)

To illustrate the secondary use of gas in the production of oil we quote in the Appendix, p. 38 from "Gas-Lift Method of Flowing Oil Wells (California Practice) Bureau of Mines Bulletin 323 by H. C. Miller 1930.

We have printed in the Appendix (p. 75) a quotation from Baker and Conklin on "Water Supply and Utilization," supported by reference to official reports of the United States Geological Survey, which illustrates the close physical analogies existing in the production of water and the production of oil and gas from sub-surface strata and their interrelation. The same analogies are confirmed in the article "Soil," 25 Americana 228, and the reports of F. H. King in the United States Geological Survey Bulletin referred to therein.

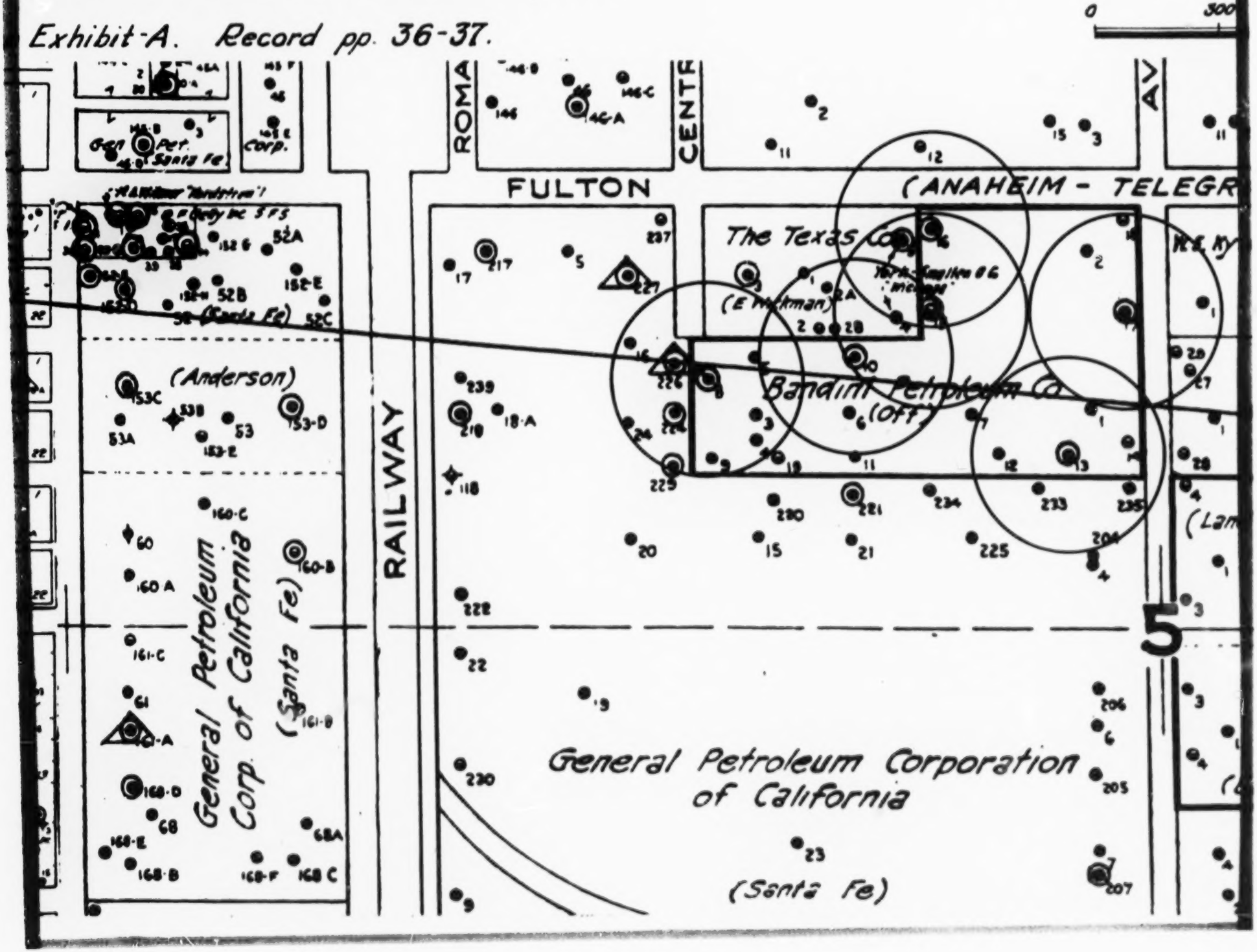
TOWN LOT AREA OF SANTA FE SPRING

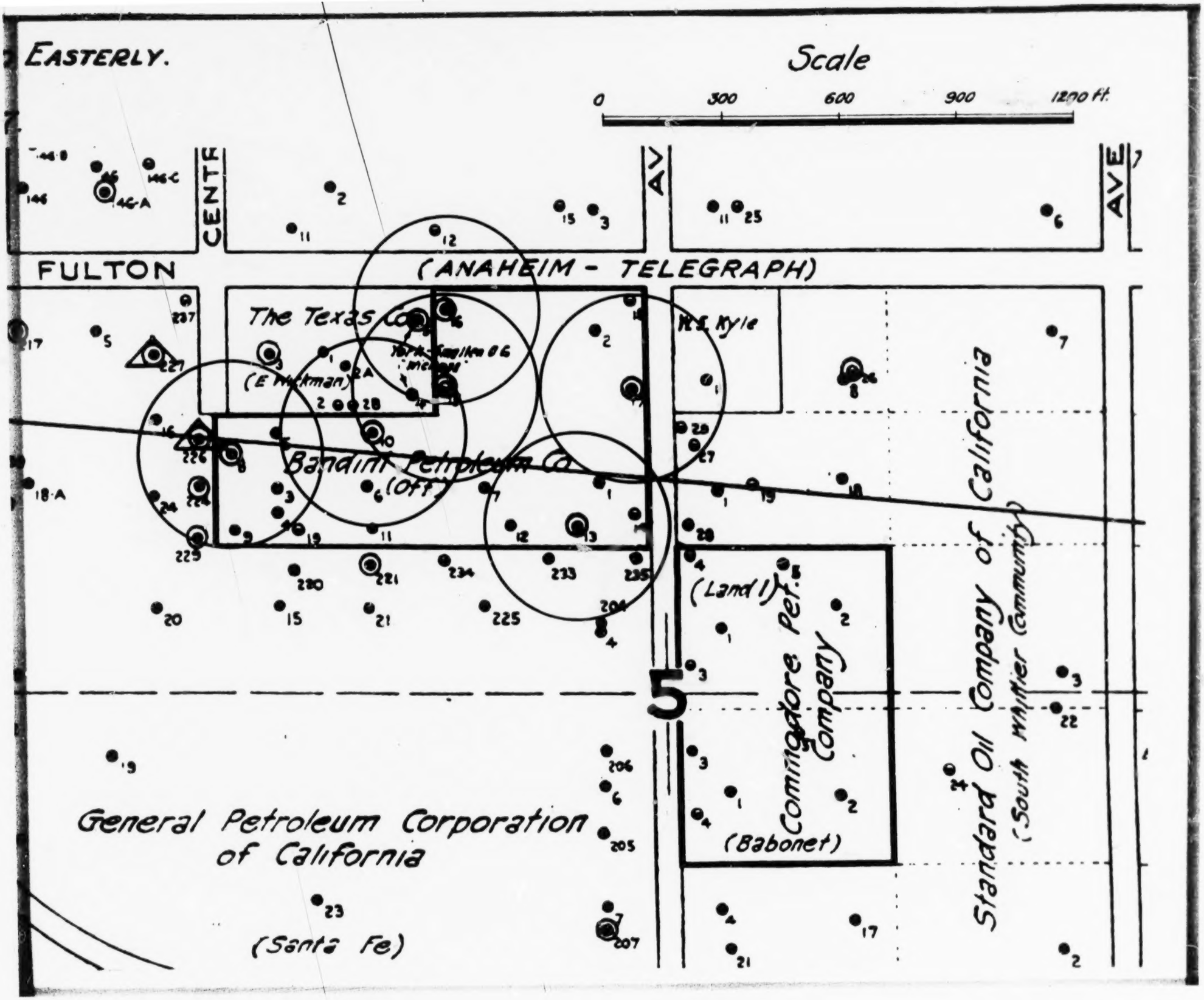
Reprint from Map Exhibit -



FE SPRINGS OIL FIELD EXTENDED EASTERLY.

Exhibit-A. Record pp. 36-37.




EASTERLY.
Scale
0 300 600 900 1200 Ft.
CENTER AV
AVE
FULTON
(ANAHEIM - TELEGRAPH)
The Texas Co
(E Workman)
Bandini Petroleum Co
(Off)
W.E. Kyle
(Land I)
Compagnore Pet. Company
(Babonet)
Standard Oil Company of California
(South Whittier Community)
5
General Petroleum Corporation of California
(Santa Fe)

IV.
ARGUMENT.

SUMMARY OF ARGUMENT.

Point A.

Police power may be asserted by each commonwealth to prevent the unreasonable waste of natural gas existing in place in geological structures within lands owned in fee simple.

Point B.

Jurisdiction of the appellee equity court must be sustained as against a writ of prohibition, if the record in that court was sufficient to sustain a finding of the facts on which its jurisdiction depended. The state courts determine their own rules of procedure and practice. On application for a writ of prohibition questioning an order of a court of general jurisdiction the only questions of fact which may be considered are those of jurisdiction.

Point C.

"Unreasonable Waste" as interpreted by the California courts of last resort meets all the requirements of certainty as a primary standard in a statute to regulate the waste of natural gas.

POINT A.

Police Power May Be Asserted by Each Commonwealth to Prevent the Unreasonable Waste of Natural Gas Existing in Place in Geological Structures Within Lands Owned in Fee Simple.

Reciting that the Act was an urgency measure and that the facts constituting the public necessity were that: "At the present time in the oil and gas producing fields within the state there is now being blown into the air and wasted daily, on the average of approximately Five Hundred Million cubic feet of gas. New fields producing heavily of natural gas are being opened up and will tend to add to the amount of natural gas being blown into the air and wasted and lost." (Stats. 1929, p. 943, Supp. p. 18) the legislature of the State of California enacted the Gas Conservation Law of 1929, the provisions of which appear in the Supplement to the Brief of Appellees on Motion to Dismiss the Appeal or Affirm the Judgment, pages 3-18. The language raising the direct issue here presented is found in Sections 8-b and 14-b of the Act as Amended, from which we quote the following:

> "The unreasonable waste of natural gas * * * is hereby declared to be opposed to the public interest and is hereby prohibited and declared to be unlawful. The blowing, release or escape of natural gas into the air shall be *prima facie* evidence of unreasonable waste." (Stats. 1929, p. 927, Supp. p. 4.)
>
> "Whenever at appears to the director * * * that the * * * lessees or operators of any well or wells producing oil and gas, or oil or gas, are causing or permitting an unreasonable waste of gas, he may institute or have proceedings instituted

> * * * to enjoin such unreasonable waste of gas * * *. Such proceeding shall be instituted in the Superior Court for the County in which the well or wells from which the unreasonable waste of gas is occurring, or any thereof, are situated. In such suits no restraining order shall be issued *ex parte*, but otherwise the procedure shall be governed by the provisions of Chapter 3, Title 7, Part II of the Code of Civil Procedure of the State of California * * *." (Stats. 1929, p. 930, Supp. p. 10.)

The chapter of the Code referred to is that relating to Injunctions.

> "The original and ultimate right to all property real and personal within the limits of this state *is in the people thereof.*" (Cal. Pol. Code, Section 40.)

> "The owner of land in fee has the right to the surface and to everything situated *permanently* below or above it." (Cal. Civil Code, Section 829.)

> "As to the precious metals fixed in the veins which hold them, they remain in tact until excavated. Oil, on the contrary, is of a fluctuating, uncertain, fugitive nature, lies at unknown depths and the quantity, extent and trend of its flow are uncertain." (*Acme Oil & Min. Co. v. Williams*, 140 Cal. 684.)

The rule of interpretation that Statutes must be read in the light of constitutional provisions is carried more nearly to its logical conclusion by the Supreme Court of California than it is by the courts of last resort in some other jurisdictions. It is the settled rule of the Supreme Court of California to read a statute as including in the text of the statute itself the provisions of the State and Federal Constitution for the protection of private rights.

Under this rule it is unnecessary to find in each statute limitations of authority otherwise necessary to complete a primary standard, if the provisions omitted from the particular statute are to be found in the State and Federal Constitutions. The legislative intent and the standard of conduct required are in every case to be derived from the three mandates of sovereign authority interpreted so as to give the proper precedence to the provisions of each. The most recent expression and application of this rule by the Supreme Court of California is to be found in the case of *People v. Globe Grain & Milling Co.*, decided December 19, 1930, 80 Cal. Dec. 625, 211 Cal. 121, not yet officially reported. In summarizing an amendment to the Fish and Game statute authorizing the Commission to grant a permit to take and use fish upon a showing that the use of the fish *"will not tend to deplete the species or result in waste or deterioration"* the Court said:

> "Here we have a condition limiting the exercise of the delegated power and, indeed, the only practicable one under the circumstances. Certainly the legislature cannot intelligently prescribe any maximum quantity for all applicants or for any one applicant; nor would it be practicable for the legislature to fix any period of time for the duration of the permit. * * * Here the statute contains the necessary limitation in the requirement that each applicant must make a showing and the commission must find, that the granting of the permit will not conflict with the fundamental object of the statute—*the conservation of food fish.*"
>
> "It is apparent that there may be varying circumstances of time, place, methods of catching fish, location where they are to be found with relation to the

location of the cannery, etc., which may legitimately justify the allowance of a larger leeway in one case than in another."

"It is of no consequence that the statute makes no reference to an equitable apportionment of the benefits to be granted. The important thing is that it contains no express grant of authority to the commission to indulge in favoritism or to make or enforce discriminatory rules. A presumption of constitutionality protects every legislative act. Being silent on the matter of apportionment of the benefits, the statute will be construed together with the constitutional provisions against discrimination, and as so construed, must be upheld. (County of San Luis Obispo v. Murphy, 162 Cal. 588; Chesebrough v. City and County of San Francisco, 153 Cal. 559; Wheeler v. Herbert, 152 Cal. 224; *In re Spencer,* 149 Cal. 396; Lent v. Tillson, 72 Cal. 404; Plymouth Coal Co. v. Pennsylvania, 232 U. S. 531; Estate of Johnson, 139 Cal. 532; Quong Ham Wah Co. v. Industrial Accident Commission, 184 Cal. 26; 12 C. J. 787, sec. 220; 5 Cal. Jur. 615, sec. 46; 628, secs. 56, 57; 6 R. C. L. 78, sec. 77.)"

In addition to the cases cited see on the sufficiency of reasonable as a standard, *Ex parte McManus,* 151 Cal. 331, 335, and *Bank of Italy v. Johnson,* 200 Cal. 1, 16.

The legislature having found that the evil of the waste of gas existed and was increasing to such an extent that an urgency measure was necessary in the public interest, the case is brought within the rule declared by this court in *Miller v. Wilson,* 236 U. S. at pages 383-384, and later quoted and applied by this court in *Radice v. New York,* 264 U. S. at pages 297-298, in the following language:

"The contention as to the various omissions which are noted in the objections here urged ignores the well-established principle that the legislature is not bound, in order to support the constitutional validity of its regulation, to extend it to all cases which it might possibly reach. Dealing with practical exigencies, the legislature may be guided by experience. Patsone v. Pennsylvania, 232 U. S. 138, 144, 58 L. ed. 539, 544, 34 Sup. Ct. Rep. 281. It is free to recognize degrees of harm, and it may confine its restrictions to those classes of cases where the need is deemed to be clearest. As has been said, it may 'proceed cautiously, step by step,' and 'if an evil is specially experienced in a particular branch of business' it is not necessary that the prohibition 'should be couched in all-embracing terms.' Carrol v. Greenwich Ins. Co., 199 U. S. 401, 50 L. ed. 246, 250, 26 Sup. Ct. Rep. 66. If the law presumably hits the evil where it is most felt, it is not to be overthrown because there are other instances to which it might have been applied. Keokee Consol. Coke Co. v. Taylor, 234 U. S. 224, 227, 58 L. ed. 1288, 1289, 34 Sup. Ct. Rep. 856."

Title to land in California continues to be held in tenure and we may properly seek to find in the ancient common law of tenure in fee simple absolute the root of the police power. In the first American and last London edition of Thomas' arrangement of Lord Coke's First Institute of the Laws of England on the plan of Sir Mathew Hale's Analysis of Littleton's Tenures (Vol. I, p. 915), the author takes up the matter in a note in which he says:

"The precise nature of it, is nowhere, perhaps, better explained than in Lord Stair's Institutes. 'It is,' says his lordship, 'essential to a fee, and common

to all kinds thereof, that there must remain a right in the superior, which is called *Dominium directum*, and withal a right in the vassal, called *Dominium utile*; * * * but by the resemblance of this distinction in law between *jura et actiones directae*, and those, which for resemblance, were reductive thereto, and therefore called *utiles*, the superior's right is called *Dominium directum*, and the vassal's *Dominium utile*, and without these the right cannot consist.' This right in the vassal to the use and profits of the land, while the direct dominion of the land remained in the lord, was, with respect to the relation between the sovereign and the subject, a new and original point of connection, and one of those marks which distinguish the feudal from every other law. * * *"

In this *"new and original point of connection"* between the *dominium directum* of the sovereign and the *dominium utile* of the tenant in fee simple absolute of land, lies the source of the modern police power to regulate the use of land.

This power of direction by the overlord was the active police power long before the advent of the Flemish weavers broke down the feudal system and made it necessary for parliament to regulate the social conditions surrounding freedmen living without allegiance in tenure outside the jurisdiction of the chartered cities of England. The police power of our own commonwealths derives from these two sources and the flow from each can be traced as can the sediment of two great tributaries in the commingled waters of a river, far below the forks. It is no longer important to determine from which of the two sources the greater or any particular contribution is made.

"It is for the state court, in cases such as this, to define rights in land located within the state." *Fox River Paper Co. v. Railroad Commission,* 274 U. S. 651, 657.

Mr. Justices White recognized each of these sources of police power in his opinion for this court in the case of *Ohio Oil Company v. Indiana,* 177 U. S. 190, stating first: "that the property of the owner of lands in oil and gas is not absolute until it is actually in his grasp and brought to the surface". And again: "Until these substances are actually reduced by him to possession he has no title whatever to them as owner * * * they do not become his property until the effort has resulted in dominion and control by actual possession." (p. 208.) "Hence it is that the legislative power from the peculiar nature of the right and the objects upon which it is to be exerted, can be manifested for the purpose of protecting all the collective owners, by securing a just distribution, to arise from the enjoyment, by them, of their privilege to reduce to possession, and to reach the like end by preventing waste." (p. 210.)

This opinion of Mr. Justice White, confirmed, extended and applied by this court in such cases as *Lindsley v. Natural Carbonic Gas Co.,* 220 U. S. 61, *Bacon v. Walker et al.,* 204 U. S. 313, *Walls v. Midland Carbon Co.,* 254 U. S. 300, has become a part of the jurisprudence of all of the oil and gas producing states with the exception of Montana, so that the Supreme Court of the State of California, in construing and sustaining the Gas Conservation Act of 1929 of that state, in *People v. Associated Oil Company, supra* (Supp. p. 29), was able to say:

"The generally accepted view, therefore, is that the property right of the owner or lessee of land in and to the gas and oil beneath the surface is not an absolute one. Such substances, because of their peculiarity in the natural state, partake more of the nature of common property, title to which becomes absolute when they are captured and reduced to possession. Because of their peculiar nature the public has a definite interest in their preservation from waste and destruction. This is true because of their character as natural resources and also because the public interest has attached by virtue of positive statutory law or by court judgment independent of statute. In seven states of the Union legislation making unlawful the unreasonable waste of natural gas has been upheld." (Citing cases.)

In the opinion by the Supreme Court of Arkansas, in *Bodcaw Lumber Co. v. Goode,* 160 Ark. 48, cited by counsel for appellants as contra (Brief, p. 61), holding that rights in oil and gas were subject to grant and distinguishing the Louisiana cases, that court said:

"In two of our neighboring states (Texas and Oklahoma), where there are extensive gas and oil fields, it has been decided by the court of last resort in accordance with the views now expressed."

After citing the case of *Texas Company v. Daugherty,* 107 Tex. 226, for the rule that while oil and gas "are in the ground they constitute a property interest," the court continued:

"In Rich v. Doneghey (71 Okla. 204) *supra,* the Oklahoma court said: 'But with respect to such oil and gas they had certain rights, designated by the same courts as a qualified ownership thereof, but

> which may be more accurately stated *as exclusive right, subject to legislative control against waste and the like*, to erect structures on the surface of their land, and explore therefor by drilling wells through the underlying strata, and to take therefrom and reduce to possession, and thus acquire absolute title as personal property to such as might be found and obtained thereby. This right is the proper subject of sale, and may be granted or reserved'."

We find no authority for the statement of counsel for appellants (Brief, p. 62) that "The Indiana statute, after the oil development had proved to be of commercial importance, was regarded as too drastic and so was repealed shortly after the decision in the Ohio Oil Company case." The Indiana statute of 1893 is still the law of that state. Section 4802, Burns' Annotated Indiana Statutes, 1926, volume 2, chapter 23, Title Conservation Department. The amendment as continued in force by the Indiana Act of 1913, p. 66, is identical in language with Section 1 of the Act of 1893, p. 300, construed in the Ohio Oil Company case.

In *Marrs v. City of Oxford,* 32 Fed. (2d) 134, *certiorari* denied in this court, 280 U. S. 573, the ordinance requiring unit development and operation of adjoining oil properties in separate ownership was sustained on the same grounds, the court saying:

> "Necessarily these regulations will encroach, when the power is exercised, on private rights; but that does not render them void. The power has its limitations and when submitted for judicial review it must appear that its exercise appropriately affords protection to the public against threatened evils. * * *

"But looking to the substance of things, as equity does, what are the rights of plaintiffs that will be encroached upon or denied to them by the enforcement of this ordinance? It is not the mere right to drill a well on one or two lots at great cost and stop with that, or to take the proportionate part of the oil and gas in the pool that might be said to lie under or be fairly attributed to those lots. * * * They extend equal opportunity to all who have an interest and eliminate the race between those having equal rights in a common source of wealth, so that some may not take all and leave others with nothing. *Under the law in Kansas, there is no property in oil and gas, because of their migratory nature, until they have been captured, though each surface owner may take without limit, unless lawfully restrained.*" (pp. 139-140.)

And so from first to last the cases cited by the Supreme Court of California [*People v. Associated Oil Co., supra,* Supp. pp. 29-30] rest on the rule that there is no ownership of oil and gas until it is reduced to possession, that the property right before possession taken by severance at the surface is real property subject to grant, and consists of the exclusive right of each landowner to acquire title to his ratable share from the common source of supply by taking possession at the surface on his own parcel, that until legislation restricts the right each owner may acquire possession of all he can obtain by drilling on his own land, and that the ratable share of each owner may be regulated and restricted by a statute to prevent waste enacted in the public interest.

In Louisiana the code provides: "The ownership of the soil carries with it the ownership of all that is directly

above and under it" (Article 505). The landowner will not be enjoined from getting "out of its land all the oil it possibly can by means of a well," even though "pumping sucks the oil from under" the adjoining owner's land, unless the complaining party was able to show further that the party complained of "is doing so with no benefit to itself" (*Higgins Oil & Fuel Co. v. Guaranty Oil Co.,* 145 La. 233). After the legislature adopted the Indiana statute to prevent waste of gas (Act 190, Stats. La. 1910, p. 313), the Supreme Court of Louisiana said, "We, therefore, hold that it is the settled jurisprudence of this state that oil and gas in place are not subject to absolute ownership as specific things apart from the soil of which they form a part; and a grant or reservation of such oil and gas carries only the right to extract such minerals from the soil. And we find with much satisfaction that our jurisprudence is in complete harmony with that which prevails throughout the land" (*Frost-Johnston Lumber Co. v. Sallings* heirs, 150 La. 858, citing cases in this court (p. 859), from courts of last resort in the oil and gas producing states, and from leading textbooks on the subject, pp. 859-860). Confirming the conclusion there reached, the Supreme Court of Louisiana has held that the property right to oil and gas in place is subject to sale, conveyance and separate taxation, and that the right when severed from the land being a servitude is prescribed by non-users for ten years (*Shaw v. Watson,* 151 La. 893). This court has regarded the Louisiana statute as a regulation of the property rights of the landowners rather than a license to produce public property (*Herkness v. Irion,* 278 U. S. 92). The residuum of title to land re-

maining in the state is that of the overlord to direct the use by the fee owner, not to enjoy the use.

We turn, therefore, to a consideration of the cases in this court sustaining these state statutes to prevent the unreasonable waste of natural gas.

Ohio Oil Company v. Indiana, 177 U. S. 190.

The General Assembly of Indiana, by statute in 1893 declared it to be unlawful for any person to permit "the flow of gas or oil from any such well to escape into the open air * * * for a longer period than two days next after gas or oil shall have been struck in such well; and thereafter all such gas or oil shall be safely and securely confined in such well, pipes or other safe and proper receptacles."

The Attorney General of the state brought the action in the state court to enjoin the Ohio Oil Company and others, from operating oil and gas wells in violation of the Act. The defendants answered. The demurrer to the answer was sustained and a preliminary injunction issued and was sustained. Mr. Justice White, near the close of his opinion, recurs to the defense of use alleged in the answer, saying:

> "First. It was argued that as the gas, before being allowed to disperse in the air, *serves the purpose of forcing up the oil,* therefore it is not wasted, hence is not subject to regulation. Second. That the answer averred that the defendant was so situated as *not to be able to use or dispose of the gas* which comes to the surface with the oil; from which it follows that the gas must either be stored or dispersed

in the air. Now, the answer further asserted that when the gas is stored and not used, the back pressure, on the best-known pump, would, if not arresting its movement, at least greatly diminish its capacity. Hence it is said the law by making it unlawful to allow the gas to escape made it *practically impossible to profitably extract the oil.* That is, as the oil could not be taken at a profit by one who made no use of the gas, therefore he must be allowed to waste the gas into the atmosphere, and thus destroy the interest of the other common owners in the reservoir of gas. These contentions but state in a different form the matters already disposed of. They really go, not to the power to make the regulations, but to their wisdom. But with the lawful discretion of the legislature of the state we may not interfere.

In view of the fact that regulations of natural deposits of oil and gas and the right of the owner to take them as an incident of title in fee to the surface of the earth, as said by the Supreme Court of Indiana, is ultimately but a regulation of real property, and they must hence be treated as relating to the preservation and protection of rights of an essentially local character. Considering this fact and the peculiar situation of the substances, as well as the character of the rights of the surface owners, we cannot say that the statute amounts to a taking of private property, when it is but a regulation by the state of Indiana of a subject which essentially comes within its lawful authority."

From the temporary injunction issued by the Court of Equity in Indiana and on appeal sustained by the Supreme Court of that State, a Writ of Error, affirmed in this court.

As quoted by Mr. Justice White, the defendant in its answer set out:

> "That before and at the commencement of this action it had in good faith been and then was, engaged in the business of producing oil by drilling therefor * * * that in carrying on said business it has expended many thousands of dollars * * * that said well was so drilled in good faith, *solely for the purpose of raising and producing oil*, the defendant not being engaged in the business of producing or transporting natural gas * * * Oil was found therein in paying quantities, and the defendant proceeded to and did save and utilize the same, paying to the land owner the stipulated royalties therefor * * * and was so operating the same solely as an oil well * * * under and by virtue of a lease to defendant by the owner of said land, granted before the commencement of this suit, under which lease defendants owns all the gas and oil in said well and under said land, and said well is of great value as an oil well. That in said well, and in the same strata of rock whence such oil was produced, there were also found at said time, quantities of natural gas, which, by its own pressure escaped through said pipes and into the open air * * * and *in so saving such oil, defendant utilized such gas as power, force and agency to raise said oil from the rock-bearing strata below* the surface of the ground, such being the usual, natural and ordinary method of raising and saving oil in such cases * * * that if such gas shall be shut into such well in such case that it will be impossible to raise or produce oil in any such well, and thereby defendant's said business with its said plant, property and profits, will be entirely destroyed and the people of said county and state will be

> deprived of the use and profits of such oil which is vastly of more value than natural gas in said well; and that the defendant says it so operated said well with the highest skill, with the most improved machinery and appliances known to the world * * * that in the territory where said well complained of is situated, there are a number of paying oil wells, owned and operated by various persons and corporations, and said field when properly developed may reasonably be expected to be a large one for the production of oil which will be and is of great value to the people of said county."

Instead of oil being discovered "in 1897 some ten or eleven years after the discovery of this pure natural gas" (Appellants' Brief, p. 58), the geology of the Indiana Trenton Limestone was reported on by Professor Orton as early as 1888, showing the usual stratification of gas at the top with the oil next below and salt water at the bottom, all under hydrostatic pressure (Appendix, p. 53). The situation in the Indiana field was very much like that in the Santa Fe Springs field.

> "In 1885 oil was discovered in the Trenton rock at a well drilled for natural gas near Lima, Ohio, which proved the beginning of developments in Northwestern Ohio and Indiana. * * * Indiana came into prominence as an oil producing state in 1891 and grew in importance until it reached its highest production in 1904 with a yield of 11,339,124 barrels." (Americana, Vol. 21, Petroleum, p. 686.)

For an authoritative review of development in Indiana see McGee and Phinney, "The Natural Gas Fields of Indiana," Eleventh Annual Report United States Geological Survey, 1889-90, at pp. 579, 605.

The Supreme Court of California has always recognized the long distances from which both oil and gas may be tributary, saying in *Acme Oil & Mining Co. v. Williams, supra,* "but when a well is developed the oil may be tributary for a long distance through the strata which holds it." The extent of gas drainage in the California field is unknown, but one well disturbs the gas pressure throughout the zone [Aff. of Bush, R. p. 43; Aff. of Gaylor, R. p. 51.] The answer of Appellants [R. p. 93] does not limit the area of gas drainage to four or five acres, but only so limits the area of oil drainage. The affidavit of Davis attached to the answer of these appellants says that the drainage area of gas is larger than that of oil [R. p. 127]. These appellants in their answer affirmatively set out that upon the property adjoining the lands operated by them are offset wells penetrating the same zones from which they are producing or expect to produce oil and gas and that the other defendants will so drill and operate such offset wells as to drain the oil and gas from the appellants' properties [R. pp. 98, 99]. The location of the appellants' properties, the wells thereon and the offsetting wells on the surrounding property, and how the development of these adjoining properties will result in drainage from the same area is illustrated on the map, Exhibit "A" [R. pp. 36, 37], an enlarged copy of which is inserted in this brief. The circles about the producing wells on appellants' Bandini lease have a scaled radius of 230 feet enclosing an area of four acres. Assuming that the holes are straight, the drainage from these wells within an area of four acres will be fully one-half from outside appellants' side lines,—a clearer case of overlap-

ping rights of adjoining landowners requiring regulation by public authority could not well be made out.

The Indiana statute to prevent the waste of gas was passed in 1893, two years after the state came into prominence as an oil producing state, and the case reached this court in 1899 while the volume of oil production was increasing. Mr. Justice White, calling attention to the holding of the Indiana courts prior to the enactment of the statute, says:

> "It is also clear from the Indiana cases cited, that in the absence of regulation by law, every owner of the surface within a gas field may prosecute his efforts and may reduce to possession all or every part, if possible, of the deposits, without violating the rights of the other surface owners."

Accordingly we find the situation in Indiana in 1893 the same both on the facts and the law as that in California in 1929.

Lindsley v. Natural Carbonic Gas Co., 220 U. S. 61.

By a bill in equity in the Circuit Court, the appellant, as owner of securities of the Natural Carbonic Gas Company, sought a decree enjoining that company from obeying, and the other defendants, officers of the State of New York, from enforcing a statute of the State of New York enacted for the protection of the natural mineral springs and to prevent the waste of its natural mineral waters. In addition to other matters, the bill alleged that the Gas Company is engaged in collecting natural carbonic acid gas from waters under its land and in compressing and selling the gas as a separate commodity; that when

the waters are lifted to the surface the gas is saved, it being conceded that a large portion of the waters pumped from the company's wells in order to obtain the gas, is not used, but is suffered to run to waste. In the Circuit Court the demurrer of the defendant state officials was sustained and the bill dismissed, the decree being affirmed in this court. The following points were passed upon and determined:

The construction of the act by the highest court of the state of New York must be accepted by the courts of the United States and be regarded by them as a part of the provision when they are called upon to determine whether it violates any right secured by the Federal Constitution. (p. 73)

Ohio Oil Company v. Indiana, supra, is cited for the rule that "One surface owner could not excessively or wastefully exercise his right of tapping the reservoir and drawing from its contents without injuriously affecting the like right of each of the others", concluding the discussion with the statement: "But were the question an open one, we still should solve it in the same way." (p. 77)

> "Each state possesses the general power to prescribe the evidence which shall be received and the effect which shall be given to it in her own courts, and may exert this power by providing that proof of a particular fact, or of several taken collectively, shall be *prima facie* evidence of another fact. * * * As respects the source of the waters, the presumption appropriately may be regarded as prompted by the fact, now well recognized, that the previous rock in which the waters exist usually is of such extent as to reach much beyond the lands of a single proprietor and to constitute a common source of supply." (pp. 82-83).

West v. Kansas Natural Gas Co., 221 U. S. 229.

Kansas Natural Gas Company, a corporation of the state of Delaware, engaged in the business of purchasing and distributing natural gas to consumers, brought the suit in the Circuit Court of the United States for the Eastern District of Oklahoma, attacking the constitutional validity of a statute of Oklahoma enacted in 1907, denying to a foreign corporation the right to engage in the business of transporting natural gas by pipe lines, and to a domestic corporation the right to transport natural gas unless it be expressly stipulated that it should only transport natural gas to points within the state of Oklahoma, and that it would not connect for the purposes of transportation or furnish natural gas, to points or persons outside of the state. The defendants were the officers of the state of Oklahoma charged with the enforcement of the law, and it is expressly alleged that it is their purpose to prevent the transportation of gas beyond the limits of the state. (p. 245)

As stated by the opinion of this court:

> "The basis of the decree of the court was that expressed in its opinion ruling upon the demurrers; to-wit, that the statute of Oklahoma was prohibitive of interstate commerce in natural gas, and in consequence was a violation of the commerce clause of the Constitution of the United States, and that being, as the court said, its dominant purpose, it would, if enforced against complainants, 'invade their rights as guaranteed by the 14th Amendment of the National Constitution' and also the Constitution of the state. 172 Fed. 545.

"These conclusions are contested, and it is asserted that the statute's 'ruling principle is conservation, not commerce; that the due process clause is the single issue.'" (p. 249)

"The provisions of the statute are not directed against waste. They are directed against any use of the gas except in the state. The right of the state 'to preserve the common supply for the equal use of all' owners is not denied by appellees. We put the question out of consideration, therefore, except incidentally, and concede the right of the state to preserve the supply of gas, as we shall hereafter set forth." (p. 251)

"And, we repeat again, there is no question in the case of the regulating power of the state over the natural gas within its borders." (p. 262)

Walls v. Midland Carbon Co., 254 U. S. 300.

The state of Wyoming, in 1919, passed an act declaring its purpose to be "The conservation of natural gas", the first section of which is as follows:

"The use, consumption or burning of natural gas taken or drawn from any natural gas well or wells, or borings from which natural gas is produced for the products where such natural gas is burned, consumed or otherwise wasted without the heat therein contained being fully and actually applied and utilized for other manufacturing purposes or domestic purposes is hereby declared to be a wasteful and extravagant use of natural gas and shall be unlawful when such gas well or source of supply is located within 10 miles of any incorporated town or industrial plant."

The Midland Carbon Company and other owners of oil and gas wells, brought the action in the District Court of the United States to enjoin the Attorney General of Wyoming, and other state officers, from enforcing the Act. The injunction was granted and on appeal to this court the judgment was reversed and the Act sustained as within the police power of the state of Wyoming, in the absence of any decision of the state courts construing the Act.

In the complaint it was alleged that prior to the enactment of the statute, the Midland Carbon Company had erected a factory for the manufacture of carbon black, located about one and one-half miles from the town of Cowley, at an expenditure of Three Hundred Seventy-five Thousand Dollars; (310); that the company's factory is so conducted as to permit no waste; that the operation of the gasoline absorption plant *and the recovery of the gasoline from the gas supplied by the wells would be impossible if the carbon plant should cease to be operated, for the reason that the gas cannot be sold to other users in that locality in sufficient quantities to render the extraction of gasoline therefrom commercially profitable.* There are other allegations asserting the use of the gas and its products and that such use is not a waste of gas. (311) The allegations were admitted by demurrer.

Mr. Justice McKenna in delivering the opinion of this court took cognizance of the fact that the statute was one to prevent the unreasonable waste of gas, the language being, wasteful and *extravagant* use of the gas, (314) and coming to the gist of the matter, said:

"The determining consideration is the power of the state over, and its regulation of, a property in which others besides the companies may have rights, and in which the state has an interest to adjust and preserve, natural gas being one of the resources of the state. And in this consideration it is more important to consider not for what a particular owner uses the gas, but the proportion of his use to that of others; or, it may be the prevention of use by others;" (p. 319)

"Manifestly, conceding a power to the state of regulation, *a comparison of the value of the industries, and a judgment upon them as affecting the state, were for it to make.* Such comparison may, therefore, be put aside. It may be, as it is deposed, that 1,000 cubic feet of natural gas converted into gasoline and carbon black may be sold much righer than can be obtained from the same amount of gas sold for fuel purposes, but it does not follow from that fact that the state may not consider, and direct its legislation by the consideration, that (and we take the averment of the companies) 1,000 cubic feet of natural gas is consumed to produce 1-3/4 pounds of carbon black and about 2/10 of a gallon of gasoline." (pp. 322-323)

"And there is great disproportion between the gas and the product, and necessarily *there was presented to the judgment and policy of the state a comparison of utilities which involved as well the preservation of the natural resources of the state, and the equal participation in them by the people of the state,* * * * as the state of Indiana could prevent the exhaustive use of gas in the production of oil, and as the state of New York could prevent the owner of land from using artificial means to obtain the

carbonated waters under his land, *the state of Wyoming has the same power to prevent the use of natural gas in the production of carbon black, * * *.*" (p. 324)

May we add,—the state of California has the same power to prevent the use of natural gas in the production of oil until the natural gas can be used without "unreasonable waste" above ground.

The use of natural gas produced in California and delivered to consumers in that state increased progressively from 39,719,000,000 cubic feet in 1918, to 212,364,000,000 cubic feet in 1927 [Supp. 97], in which year there were 745,440 domestic consumers [Supp. 95]. In 1928 there were 769,000 domestic consumers in California, that being exceeded only in the State of Ohio, and being approached only in the State of Pennsylvania, where there were 615,000 domestic consumers [Supp. p. 81]. In the following year, 1929, the number of domestic consumers in California reached a total of 1,239,000, being the largest number in any state (International Year Book 1930, p. 297). Waste by blow to the air in 1928 amounted to 77,000,000,000 cubic feet, and for the first seven months of 1929 to nearly 128,000,000,000 cubic feet, of which total waste over 56,000,000,000 cubic feet was from the Santa Fe Springs Field alone [R. 57-58]. The comparative increase in the gas blown to the air is graphically illustrated by the blue prints attached to the affidavit of Brown appearing in the record here between pages 60 and 61.

Under these circumstances the Legislature of California could not in reason have disregarded requiring an

adjustment between two great industries of natural gas and petroleum oil on which the people of the state had become so dependent and whose products of oil and gas were of necessity severed from the land and produced at the same time.

It has long been the law that the Legislature of each commonwealth in a proper case may impose a burden upon specific lands in proportion to the estimated special benefits which those lands may receive from the burden imposed, the limitation upon the power being that it must appear that the character of the burden is such that it confers some general benefit on the public as well as a private benefit on the landowners. This is the basis of the rule where the burden imposed is a money charge (*Fallbrook Irr. Dist. v. Bradley*, 164 U. S. 112, 163, *Wurts v. Hoagland*, 114 U. S. 606), or a restriction on the use of the land by zoning ordinances (*Washington ex rel. Seattle Title Trust Co. v. Roberge*, 278 U. S. 116, 120-121, *Gorieb v. Fox*, 274 U. S. 603, *Euclid v. Ambler Realty Co.*, 272 U. S. 365). The control of the commonwealth over swamp lands is no more complete, and the reason for such control no more persuasive either from the necessities of the public or the interlocking interests of the private owners than over an oil field. Relying upon authorities in this court, the Supreme Court of California has said in *People v. Sacramento Drainage Dist.*, 155 Cal. 373, 381:

> "The question of the power of the legislature, in a proper case, to impose a burden in the nature of a tax upon specific lands, in proportion to the estimated special benefits which those lands will receive from the work done, may not be doubted. The limi-

> tation upon its power,—it is well settled,—is this, that to sustain such a law it must appear that the character of the work is such that its performance confers some general benefit on the public as well as a private benefit on the landowner. And that the improvements here contemplated are of such character, has long been definitely settled. So complete is the control of the state over swamp and overflowed lands, that its power to provide for reclamation of them is not limited to those lands the title to which was acquired under the Arkansas Act, but it exists as to all swamp and overflowed lands in the state, even if the title was derived from a Spanish or Mexican grant. (Hagar v. Yolo Co., 47 Cal. 222; Hagar v. Reclamation Dist., 111 U. S. 701, (4 Sup. Ct. 663); Fallbrook Irr. Dist. v. Bradley, 164 U. S. 112, 163, (17 Sup. Ct. 56).)"

The benefit of the private owner is in the more economical management of adjoining lands held in severalty, the great increase in the ultimate production of oil, the larger returns from gas by spreading its use over a period of years, all of which arise by reason of the peculiar natural condition of the structure containing gas and oil in relation to the surface ownerships in severalty. The benefit conferred upon the public is the conserving for future use of large quantities of natural gas which necessarily must be produced with the oil and cannot be stored above ground. The distribution of the burden of temporarily reduced production of gas from the field among the producers in the field according to their respective rights upon reducing the waste under the statute, was left by the California statute of 1929 to the court of equity in an action brought in the name of the People of the State to

which the producers were parties, each of whom was served with process and their rights carefully guarded by the provision in the statute against any *ex parte* injunction and by the right of appeal to the Supreme Court of the State. The injunction challenged reserved the right of the court on application to modify the injunction to correct any inequities. Any amended order and the final decree may again be subjected to the scrutiny of the Supreme Court on appeal. It is submitted that by these provisions every requirement of "due process of law" under the Federal Constitution was preserved to appellants and other operators in the field.

These instances of public improvement districts where the burdens are distributed over the parcels of land according to their respective ultimate benefits, and these limitations upon the use of real property by zoning ordinances under proper and reasonable classifications are all cases where the owners failed to voluntarily cooperate in the use of their property to such an extent as to have their misuse become a matter of public interest. Such cases and this case come properly within the rule stated by this court in *Noble State Bank v. Haskell*, 219 U. S. 104, 112, as follows:

> "The power to compel, beforehand, *co-operation*, and thus it is believed, to make a failure unlikely and a general panic almost impossible, must be recognized, if government is to do its proper work, unless we can say that the means have no reasonable relation to the end."

Herminghaus v. Southern California Edison Company, 200 Cal. 81.

The holding in this case is the very antithesis of the rule for which it is cited by counsel for appellants. The defendant was not a riparian proprietor and had no right to the use of waters of the San Joaquin River, either as a correlative proprietor or otherwise, but was a stranger on the stream seeking to take from plaintiff the water which belonged to plaintiff's land and make use of it for defendant's profit in derogation of plaintiff's rights as riparian proprietor. In granting an injunction to protect plaintiff's right against such an invasion, the Supreme Court of California said:

> "Each person through whose land a watercourse flows has (in common with those in like situation) an equal right to the benefit of it as it passes through his land, for all useful purposes to which it may be applied; and no proprietor of land on the same watercourse has a right *unreasonably* to divert it from flowing into his premises, or to obstruct it in passing from them, or to corrupt or destroy it.' In a later portion of the opinion this court said (page 394): 'By our law the riparian proprietors are entitled to a reasonable use of the waters of the stream for the purpose of irrigation. What is such reasonable use is a question of fact, and depends upon the circumstances appearing in each particular case.'" (p. 95)

> "Being an upper riparian owner along said stream and the tributaries thereof, it is entitled to the benefit of whatever reasonable waste or diminution in the volume of said waters occurs during and in the course of the reasonable exercise of its riparian rights therein." (pp. 108-109)

> "If the state were here assaying to uphold an effort on its part to work out impartially, unselfishly and in the interests of the whole people some general plan or system for the equitable adjustment of rights and uses in its flowing streams with a view to the conservation, development, and distribution of the dynamic forces and generative and fertilizing fructibilities of their waters, it might well be argued that public policy, public interest, and a most liberal interpretation of the police powers of the state might rightfully be invoked in support of such an effort. But can the same be properly said or claimed in a case wherein one or many privately owned and operated institutions, organized primarily for personal and private gain, and only incidentally and secondarily assuming to act in the public interest and welfare, are engaged in controversies in the courts with other private individuals or associations over the asserted and disputed property rights and interests of each of the respective parties to such controversies? We do not feel called upon in this case to so declare." (p. 120)

In the instant case the state is here "assaying to uphold an effort on its part to work out impartially, unselfishly and in the interests of the whole people some general plan or system for the equitable adjustment of rights and uses" in the natural reservoirs of gas under the separate holdings of many proprietors where experience has demonstrated that the rights of all will be seriously injured by the avarice and cupidity of one or more landowners refusing to cooperate in an orderly production from the common structure from which each is entitled to acquire his fair share of the oil and gas content which no one owns until he takes possession at the surface.

This the state has done by an act to prevent the unreasonable waste of natural gas, "with a view to conservation, development and distribution of the dynamic forces contained in these geological structures far beneath the surface of the earth." It was argued, and the argument was sustained by the District Court of Appeal and by the Supreme Court of the State of California, "that public policy, public interest, and a most liberal interpretation of the police powers of the state might rightfully be invoked in support of such an effort", and the argument was sustained upon the reasoning and decisions of this court so many times reaffirmed here as to have become a part of the jurisprudence of the oil and gas producing states of the Union. The Supreme Court of California properly held that the same could not be "said or claimed in a case wherein one or many privately owned and operated institutions, organized primarily for personal and private gain, and only incidentally and secondarily assuming to act in the public interest and welfare, are engaged in controversies in the courts with other private individuals or associations over the asserted and disputed property rights and interests of each." The genesis of the rule distinguishing the right to control the waste of natural gas arose in this court not in a case where privately owned and operated institutions organized primarily for personal and private gain sought to have adjudicated their several interests in the common source of supply of natural gas, but in a case brought by the attorney general of the State of Indiana to enforce the statute of that state to prevent the unreasonable waste of a commodity by one of several owners entitled to ac-

quire title to a portion of a common supply of natural gas by reducing it to possession at the surface of the ground. The argument of counsel for appellants may well be answered in the language of Mr. Justice White, answering the similar arguments of appellants in the case of *Ohio Oil Co. v. Indiana, supra,* where he said:

> "The confusion of thought which permeates the entire argument is two fold: First, an entire misconception of the nature of the right of the surface owner to the gas and oil as they are contained in their natural reservoir, and this gives rise to a misconception as to the scope of the legislative authority to regulate the appropriation and use thereof. Second, a confounding, by treating as identical, things which are essentially separate; that is, the right of the owner of land to bore into the bosom of the earth, and thereby seek to reduce the gas and oil to possession, and his ownership after the result of the borings has reached fruition to the extent of oil and gas by himself actually extracted and appropriated. In other words, the fallacy arises from considering that the means which the owner of land has a right to use to obtain a result is in legal effect the same as the result which may be reached. We will develop the misunderstanding which is involved in the matters just stated." (177 U. S. 202.)

Developing the misunderstanding which was involved in the argument of counsel, Mr. Justice White quoted from an earlier case arising in Pennsylvania, as follows:

> "In Hague v. Wheeler, 157 Pa. 324, 22 L. R. A. 141, 27 Atl. 714, the question involved in the cause was the right of a land owner who had a gas well on his own land to complain of the escape of gas from a well situated on the land of another. After

adverting to the rule embodied in the maxim, *Sic utere tuo ut alienum non laedas*, and after referring to the exceptional nature of the right to acquire ownership in natural gas and oil, it was decided that the complainant was not entitled to relief. The court said (157 Pa. 340, 341, 22 L. R. A. 147, 148, 27 Atl. 719, 720):

"'Now it is doubtless true that the public has a sufficient interest in the preservation of oil and gas from waste to justify legislation upon this subject.'"

The difference in the property right to natural gas and in the property right to coal or rock or gravel in place decided by this court in *Ohio Oil Co. v. Indiana, supra*, together with the interest of the state in the conservation of the supply of natural gas was most clearly pointed out by Mr. Justice Van Devanter in writing for this court in *Pennsylvania v. West Virginia*, 262 U. S. 553, 58 :

"Natural gas is found at pronounced depths in porous strata—usually sand rock—constituting a natural reservoir, and is brought to the surface and reduced to possession through wells drilled into the containing strata. When a surface owner thus reduces it to possession he becomes its owner and it becomes a subject of commerce, like any product of the forest, field, or mine. In the inclosing strata it is under great pressure, called rock pressure, which causes it to flow out rapidly when the strata are penetrated. If one surface owner drills wells and begins to draw off the gas, others desiring to exercise their common right must take the same course, for otherwise the gas under their lands may be drained out by those wells. After the gas is drawn from the inclosing strata there is no practicable mode

of storing and holding it. It must be used promptly. Its chief use consists in producing heat and light by burning it. The points of use generally are in centers of population or of industry more or less remote from the places of production. The intervening transmission is effected through pipe lines. The normal rock pressure will carry the gas considerable distances, and when that pressure wanes or is inadequate it can be supplemented by using compressors."

"The attitude of the complainant states is not that of mere volunteers attempting to vindicate the freedom of interstate commerce or to redress purely private grievances. Each sues to protect a twofold interest,—one as the proprietor of various public institutions and schools whose supply of gas will be largely curtailed or cut off by the threatened interference with the interstate current, and the other as the representative of the consuming public whose supply will be similarly affected. Both interests are substantial and both are threatened with serious injury.

"Each state uses large amounts of the gas in her several institutions and schools,—the greater part in the discharge of duties which are relatively imperative. A break or cessation in the supply will embarrass her greatly in the discharge of those duties and expose thousands of dependents and school children to serious discomfort, if not more. To substitute another form of fuel will involve very large public expenditures.

"The private consumers in each state not only include most of the inhabitants of many urban communities, but constitute a substantial portion of the state's population. Their health, comfort, and wel-

> fare are seriously jeopardized by the threatened withdrawal of the gas from the interstate stream. This is a matter of grave public concern in which the state, as the representative of the public, has an interest apart from that of the individuals affected. It is not merely a remote or ethical interest, but one which is immediate and recognized by law." (pp. 591-592)

In *Bacon v. Walker,* 204 U. S. 311, defendant in error brought the action for damages alleged to have accrued to them by the violation by the plaintiff in error of a statute of the State of Idaho declaring it unlawful to herd sheep on land or possessory claims of other persons to the public domain within two miles of the dwelling house of the owner of such possessory claim. Citing *Ohio Oil Co. v. Indiana, supra,* Mr. Justice McKenna, speaking for this court, said:

> "The object of the statute was to prevent the waste of gas * * *. The statute was sustained as a constitutional exercise of the power of the state, on account of the peculiar nature of the right and the objects upon which it was exerted, for the purpose of protecting all of the collective owners." (316)

Making application of the principle, Mr. Justice McKenna continued:

> "Does the herding or grazing of sheep necessarily, and because of its unwarrantable character, work an injury to the public? * * * It (police power) extends to so dealing with the conditions which exist in the state as to bring out of them the greatest welfare of its people. This is the principle of the cases which we have cited. But the statutes have justification on the grounds which plaintiff in error urges as determinative, and on those grounds they were sustained by the supreme court of the state. They were deliberate enactments made necessary by and addressed to the conditions which existed." (318)

POINT B.

Jurisdiction of the Appellee Court Must Be Sustained as Against a Writ of Prohibition if the Record in That Court Was Sufficient to Sustain a Finding of the Facts on Which Its Jurisdiction Depended. The State Courts Determine Their Own Rules of Procedure and Practice. On Application for a Writ of Prohibition Questioning an Order of a Court of General Jurisdiction the Only Questions of Fact Which May Be Considered Are Those of Jurisdiction.

The application for the writ of prohibition was to the District Court of Appeal of the State of California according to the statutory procedure and practice of that state. The construction of these statutory provisions was for the state courts of last resort. The record they considered will be considered here, and the paper they found in the record and properly certified here will be considered by this court. The District Court of Appeal to whom the application was made found that there was sufficient evidence in the record to sustain the jurisdiction of the appellee court to pass on the issue of its own jurisdiction and to sustain the injunction. To this point the District Court of Appeal said:

> "And we here direct attention to the determination of the respondent court that 'there appears to be an unreasonable waste of natural gas in the Santa Fe Oil Field,' and 'that the evidence available . . . shows that the unreasonable waste of natural gas in said field may be substantially reduced and that the equities of all parties may be fairly conserved by a preliminary injunction which will limit the waste of gas by restricting the production thereof to a

quantity reasonably in excess of the present outlets for beneficial use above ground, etc., etc.' It does not appear from the facts presented to us that in so far as the particular case before us is concerned the court exceeded its jurisdiction in finding as we have already quoted." [R. 217.]

Appellants' petition to the District Court of Appeal, among other things, alleged as follows:

"On September 11, 1929, the people of the State of California * * * commenced an action * * * a true copy of which complaint, marked Exhibit I, is annexed to this petition and hereby made a part hereof to the same force and effect as if set out at length in the body of this petition." [R. pp. 1-2.]

"3. On said date said Superior Court issued an order to show cause * * * a copy of said order together with a copy of the affidavits of Reed D. Bush, Emile Huegenin, E. G. Gaylord and Claud C. Brown * * * were thereafter served upon petitioners and filed in said action. A true copy of each of said affidavits is annexed hereto and marked respectively, Exhibits III, IV, V, VI, in the order above named, and they are hereby referred to and made a part hereof." [R. p. 2.]

"All of said pleadings and affidavits were received in evidence upon the hearing of said order to show cause, in addition to oral and documentary evidence." [R. p. 3.]

The California statute applicable to writs of prohibition provides:

"Writ of prohibition defined. The writ of prohibition is the counterpart of the writ of mandate. It arrests the proceedings of any tribunal, corporation,

board, or person exercising judicial functions, when such proceedings are without or in excess of the jurisdiction of such tribunal, corporation, board or person." (Sec. 1102, Code of Civil Procedure, Stats. 1919, p. 2291.)

"*Hearings by court.* If no answer be made, the case must be heard on the papers of the applicant. If the answer raises only questions of law, or puts in issue immaterial statements not affecting the substantial rights of the parties, the court must proceed to hear or fix a day for hearing the argument of the case. (Sec. 1094, Code of Civil Procedure, Stats. Code Amendments 1873-4, p. 345.)

By the allegations of plaintiff's petition for a writ of prohibition, the complaint of the plaintiff people of the state in the superior court and the affidavits of the witnesses, Bush, Huegenin, Gaylord and Brown were as much a part of the papers of the petitioners as was their own answer to the complaint and the affidavits of witnesses in support thereof. This is the construction given to the statute by the courts of last resort of California, and is the only construction which could have been given consonant to the rules confining the use of a writ of prohibition in matters of jurisdiction and not permitting it to be substituted for appeal. In denying another writ of prohibition, in *Truck Owners etc. Inc. v. Superior Court,* 194 Cal. 146, 155, "If the superior court has jurisdiction to entertain the action, it has the power to define the right sought to be protected * * *. If the judgment of the superior court be incorrect it may be reversed on appeal but not on prohibition. This is the rule in this court." (*Ex parte Alix,* 166 U. S. 136; *Mt. Vernon-Woodberry*

etc. Co. v. Alabama I. P. Co., 240 U. S. 30; *Swift & Company v. U. S.,* 276 U. S. 311.)

The petitioners for the writ of prohibition necessarily make the record before the Superior Court in which the preliminary injunction was granted a part of their papers on application for the writ. Because, if there was a conflict in the evidence, or if the question of jurisdiction had to be determined by findings of fact on the evidence as to which there was an issue in that court, then the writ of prohibition is not the proper remedy, but the court before whom the action is pending, must find on the fact lying at the basis of the issue of jurisdiction, and the remedy of the aggrieved party is by appeal.

Murphy v. Superior Court, 84 Cal. 592.

The allegation in the petition for the writ as to what appears by the uncontradicted evidence is merely a conclusion of law, the affirmance or denial of which "raises only question of law, or puts in issue immaterial statements." The contents of the exhibits to the petition, made a part thereof, will control over the general allegation of what the evidence shows. As stated by the Supreme Court of California in *Gosewich v. Doran,* 161 Cal. 511, p. 515:

> *"As against the showing of the exact contents of the pleading which was thus filed against the plaintiff, his allegation in his complaint for libel that the publications charging him with misconduct were not pertinent or material is a mere conclusion of law,*

> *which is not admitted by the demurrer (Glide v. Dwyer,* 83 Cal. 477, (23 Pac. 706); *Burling v. Newlands,* 112 Cal. 476, (44 Pac. 810), and must be disregarded as contrary to the facts alleged."

The same rule has been more recently stated by that court in *Kidwell v. General Petroleum Corp.,* decided June 1, 1931, 81 Cal. Dec. 906, as follows:

> "In view of the fact that the lease is made a part of plaintiffs' second amended complaint and that its terms are clear and unambiguous, the allegations of the second amended complaint regarding its legal effect, the intent of the parties thereunder, the character of the leased property, or any other like statement become immaterial in determining whether the pleadings state a cause of action. Such allegations may be disregarded as surplusage. * * * We must, therefore, resort to the terms of the lease itself for the purpose of determining the rights of the parties thereunder."

This is the same rule stated and applied by this court in the case of *Bank of California v. Roberts,* 248 U S. 497, 500.

In the case of *Favorite v. Superior Court,* 181 Cal. 261 (cited by Appellants' Brief, p. 14), the court denied a writ of prohibition to prevent the Superior Court from proceeding in a cause pending in that court on the alleged ground the judge presiding was disqualified, saying:

> "There is no information obtainable from the record to show that ownership at that date would disqualify him. The cause was submitted, as we have said, upon a demurrer to the petition. The petition

> does not set forth the complaint in the action pending in the superior court, nor purport to state the substance thereof."

In the present case the petitioners not only set forth the complaint and the affidavits in support of the complaint, but by express allegation in their petition made them a part thereof. [R. pp. 1-2.]

The jurisdiction of the court to make the particular preliminary injunction to which objection is made depends upon whether the remedy by injunction was germain to the cause of action before the court. By the Gas Conservation Statute new rights were created, but the remedy provided was in the court of general jurisdiction according to the usual practice of that court in granting injunctions in all cases. "In such suits no restraining orders shall be issued *ex parte* but otherwise the procedure shall be governed by the provisions of Chapter III, Title VII, Part II, of the Code of Civil Procedure of the State of California." [Sec. 14b, Stats. 1929, p. 930, Supp. p. 10.]

This limitation on the power of a court that its orders must be germain to the action is no more than that it must act judicially. Examples are well stated in the opinion of this court in *Windsor v. McVeigh,* 93 U. S. 274, 282, quoted and followed in Baar v. Smith, 201 Cal. 87, 100, where the court says:

> "If, for instance, the action be upon a money demand, the court, notwithstanding its complete jurisdiction over the subject and parties, has no power

to pass judgment of imprisonment in the penitentiary upon defendant. If the action be for libel or personal tort, the court cannot order in the case a specific performance of a contract. If the action be for the possession of real property, the court is powerless to admit in the case the probate of a will."

In *Jacobsen v. Superior Court,* 192 Cal. 319, 325, so greatly relied upon by appellants, it was held that the jurisdiction of the Superior Court in equity was separate and distinct from its jurisdiction in eminent domain, and that the Superior Court in equity would not have jurisdiction by a temporary injunction to oust the owners of real property, until by an action in eminent domain the public had acquired the right. In *People v. Associated Oil Co., supra,* the Supreme Court of the State of California by taking jurisdiction of the appeal from the injunction necessarily held that the Superior Court would have jurisdiction to grant the injunction. The matter is the construction of a state statute by the courts of last resort of the state, and no Federal question is involved in such matters of procedure and practice. *(North Laramie Land Co. v. Hoffman,* 268 U. S. 277-279.) It remains, however, for this court "to inquire whether the statute as interpreted and applied by the state court denies rights guaranteed by the constitution" *(North Laramie Land Co. v. Hoffman, supra).*

These are the two Federal questions stated by the District Court of Appeal: *first,* the power of the state to prohibit the waste of natural gas, and *second,* the degree

of certainty required in the state statute to meet the requirements of "due process of law." [Statement of Appellees as to Jurisdiction on Appeal, p. 6; Opinion of District Court of Appeal, R. p. 202.] Appellees have not claimed these Federal questions were not formally raised, but moved to dismiss the appeal or affirm the judgment below upon the distinct ground that each of these questions had been so explicitly determined in this court as to no longer present a Federal question for review. (Statement of Appellees as to Jurisdiction, pp. 5-7.)

The California courts take judicial notice of scientific facts, including the progress of the natural gas and oil industries, and refresh their judicial knowledge by reference to technical papers (*People v. Associated Oil Co., supra,* Supp. pp. 33-34, 211 Cal. 106). This court follows the same rule. (*Liberty Warehouse Co. v. Burley T. G. Coop.,* 276 U. S. 71; *Schollenberger v. Pennsylvania,* 171 U. S. 1; *Jacobsen v. Massachusetts,* 197 U. S. 11.) Where the constitutionality of a statute is called in question by an application for a writ of prohibition or by other collateral attack, the court may confine itself to the statute and matters of which it takes judicial knowledge. (*Stevenson v. Colgan,* 91 Cal. 652; *Frohliger v. Richardson,* 63 Cal. App. 209, 214.) Where there has been a trial on the merits with findings, the court may also consider clear and satisfactory evidence in the record of the particular case (*Abbey Land etc. Co. v. San Mateo,* 167 Cal. 434, 437)

POINT C.

"Unreasonable Waste" Meets All of the Requirements of Certainty as a Primary Standard in the California Statute to Regulate Waste of Natural Gas as Construed and Applied by the Courts of Last Resort of That State.

> "It would seem, therefore, that the legislature has plainly adopted the standard so expressed, viz.: that gas may not be produced, under existing conditions where the production thereof so greatly exceeds the market demands therefor, in quantities exceeding a reasonable proportion to the amount of oil produced, as the standard to be applied and beyond which the production is prohibited as being an unreasonable waste of natural gas."

When this court is asked to determine whether or not there is a sufficient standard of waste prescribed by the California law to meet the requirements of the Federal Constitution, it is not the bare statute as it came from the legislature which we have to consider, but that statute interpreted, construed and applied by the courts of last resort of the state. Here we are beyond the process of a verbal construction of the legislative language to the extent that we can find aid in the decisions and opinions of the courts of last resort of the state. In the instant case we have three such opinions; the one rendered by the District Court of Appeal denying these appellants a writ of prohibition, from which this appeal is prosecuted, and two in the Supreme Court of California, the one denying a writ of supersedeas and the other sustaining the very in-

junction here questioned. It is the settled practice in the Supreme Court of California, where the subject regulated is within the scope of the police power of the state, that a charge of discrimination or lack of reasonable relation between the evil to be prevented or a charge of uncertainty in defining the line between what is allowed and what is denied must be supported by facts in the record sufficient to overcome the general presumption of constitutionality. See authorities collected in *People v. Globe Grain & Milling Co., supra.* Such also is the rule in this court. *(Lindsley v. Natural Carbonic Gas Co.,* 220 U. S. 61, 79; *Wampler v. LeCompts,* 282 U. S. 172, 174.)

The statute will be taken as it is left by the Supreme Court of the State of California with any unconstitutional paragraphs and sections disregarded by that court disregarded here *(Lindsley v. Natural Carbonic Gas Co., supra),* and the meaning affixed to the statute by that court will be the meaning considered here *(Quong Ham Wah Co. v. Industrial Accident Commission,* 255 U. S. 445). Outside of what is recognized as public utility or monopoly service "this court has held that the power of the state stopped short of interference with what are deemed to be certain indispensable requirements of the liberty (of contract) assured, notably with respect to the fixing of prices and wages." *Near v. State ex rel Olson,* No. 91, decided June 1, 1931. The statute questioned here is neither a price fixing nor a wage regulating law. The subject matter, the severance and production of natural gas, is clearly within the field of regulation under the police power, as a natural resource within the land and not yet a commodity of commerce *(Ohio Oil Co. v. In-*

diana, supra); as a statute framed and shaped to suit the economic conditions of the state, where the right of each landowner impinges upon the rights of each other landowner in the same source of supply *(Bacon v. Walker, supra);* and as an adjustment of two great industries in their relations to the people of the state *(Walls v. Midland Carbon Co., supra).* With these assumptions, we turn to an examination of the California statute as it comes from the courts of last resort of that state, to find the standard of conduct required of those operating oil and gas wells in the Santa Fe Springs oil field in respect to the waste of natural gas. The definition of a standard is directed to those engaged in the particular business regulated by the statute. Farmers and bankers are not engaged in the production of natural gas with its associated oil from pressure zones six and seven thousand feet beneath the ground. Rules and regulations and standards of conduct for the production of oil and gas are directed to those familiar with the learning in respect to these geological structures, and their handling. They are as properly chargeable with the common knowledge of the industry as bankers were held properly charged with knowledge of what was meant by "liabilities," "agencies," and by "assets of sufficient value to pay within a reasonable time in the ordinary course of business." *(State v. Bevins,* Supreme Court of Iowa, May 16, 1930, 230 N. W. 856, affirmed in this court, *Bevins v. Iowa,* 282 U. S. 815.)

Any standard necessarily has relation to the thing to be measured, and the presumed knowledge of the persons required to do the measuring. By the statute as con-

strued by its courts of last resort, the Legislature of California clearly expressed its intent to limit the quantity of gas to be blown into the air and to limit the quantity of gas to be used in bringing oil out of a well, not in absolute quantities, but in balanced proportions according to the dictionary definition of waste as "needless destruction, or useless consumption," and having regard to the correlative rights of neighboring operators. To make it plain that this definition of "waste" was intended rather than other definitions, the legislature used the characterizing adjective "unreasonable." The Supreme Court of the state has adopted this construction of the legislative language. These defendant appellants, with their wells snuggled along the boundaries of their several properties, knew that their production of both oil and gas from first to last came in part from beneath the lands of other proprietors. They state affirmatively that they were releasing to the air over 40% of the gas produced by them. In addition to this, the statute in express language served each of them with notice that upon blowing any gas into the air the operator assumed the burden of producing evidence to show that such release of gas to the air was reasonable. The rule of law applicable to oil and gas properties which gave the operator the right to draw any oil or gas from beyond the vertical planes of his holdings, *contained within itself* the limitation that "his power as an owner is absolute until the legislature shall, in the interest of the public as consumers, restrict and regulate it by statute." (*Hague v. Wheeler,* 157 Pa. 324, *Ohio Oil Co. v. Indiana,* 177 U. S. 204-205.) Each operator drawing any gas from beyond his property lines did so subject to this legislative power

inherent in the definition of the property right he was exercising. Each operator was charged with knowledge of the position of his well on the structure, of his production ratio of oil to gas, and the increase or decrease of that ratio, of the solution gas-oil ratio in the production zone, of the burden cast on him by releasing gas to the air, and of the location of his boundary lines. These things were before each appellant as a part of its knowledge when by releasing gas into the air it undertook the burden of producing evidence to controvert the *prima facie* case that its release of gas to the air constituted unreasonable and, therefore, unlawful waste. On the application for the preliminary injunction the plaintiff people went forward with affirmative proof of the great quantity of the gas released to the air in the state, in the Santa Fe Springs Field by all operators and by each of these appellants, with proof of the gas-oil ratio which would produce all the gas which could be made use of from the field and with proof of the increasing demand for the gas by domestic users, which demand would absorb all the gas if production was distributed over a few years instead of all being blown out into the air in a single year.

It may very well be that the injunction subjected to attack here did not go far enough in preventing waste of gas under the statute. In this respect it must be remembered that the injunction challenged is a preliminary injunction, subject to modification by the court, and in any event intended only to preserve the subject matter of the suit until the rights of the parties could be determined by trial. It probably would have been better, looking back from the vantage point of today if the preliminary in-

junction, after limiting the production of gas by each operator as it did, had continued and by fixed terms prohibited any production in excess of 2500 cubic feet of formation gas to a barrel of oil, as prayed for by the plaintiff people. As the pressure about each well was lowered and the gas-oil ratio increased the well should be placed on "gas lift" and production continued without increasing the production rate of *formation* gas. If the appellee equity court had jurisdiction, it is not to be subjected to a writ of prohibition because it did not sufficiently recognize the rights of the plaintiff people on the first application made. If the equity court had jurisdiction to grant an injunction, it is not to be subjected to a writ of prohibition because in the first instance, by preliminary order, it confined itself to dealing with the main or primary restraint of unreasonable waste and failed to prescribe the subdivisions of that part of the gas production which should be allowed to particular wells on each particular parcel of property of each particular operator. The duty imposed upon the equity court in the first instance did not extend beyond the necessity for its action. If the real matter for a preliminary injunction was to determine how much of the allowed release of gas should be permitted to each property holding, there is nothing in the law to prevent the equity court from letting the operators apportion their respective shares of gas among their particular wells on their particular operating land parcels, subject always to the right of the court to modify its order and make such apportionment to particular wells, should equity require it. This right of modification was particularly reserved in the order made. For an order after this

manner in an analogous situation, see the opinion of this court in *Akron C. & Y. Co. v. United States,* 261 U. S. 184, 201-203.

The District Court of Appeal of California in its opinion on the decision challenged here finds the rule for ascertaining the line between unreasonable waste and reasonable use in the decisions of the court in that state determining the right of production and use of subterranean waters, where if the "natural supply is not sufficient for all such owners, each is entitled only to his reasonable proportion of the whole, and that each may apply to the courts to restrain an injurious and unreasonable taking by another." Applying this rule the District Court of Appeal said:

> "It is argued, however, that the statute involved herein does not proceed upon the theory of correlative rights, but only upon the policy of conserving or preserving the common supply. We cannot assent to this statement or construction of the enactment. It is true that section 8b of the act declares the 'unreasonable waste of natural gas . . . to be opposed to the public interest' and 'to be unlawful,' but it is also apparent from a reading of the entire act *that unreasonable waste of gas is considered to be the production of an undue proportion of gas to the amount of oil, in the particular field involved, by one surface owner as against others, in those instances where the gas is not conveniently necessary for the 'generation of light, heat, power or other industrial purpose'.*" [*Bandini v. Superior Court,* R. p. 210.]
>
> "Sufficient has been said to effectually dispose of the remaining argument of the petitioners and demonstrate that it is founded on a misconception of the legislative intent. Their argument is in effect that

they are not producing an undue proportion of gas when the gas production is measured by the oil from one specific well. But this is obviously not the purpose of the law, as may clearly be indicated by a single illustration. Suppose a well is drilled and comes in, as what is commonly termed 'a gasser,' that is, a well which produces an insignificant quantity of oil. Conceivably such a well might drain the field of its supply of gas, leaving the oil therein unrecoverable, to the great and irreparable injury of the other surface owners. We have instanced an extreme possibility, but our interpretation of the act is that it was intended to remedy a lesser, but nevertheless unreasonable, degree of waste of the same character."]*Bandini v. Superior Court*, R. pp. 216-217.]

The Supreme Court of the state found the same definition of unreasonable waste, saying:

"It would seem, therefore, that the legislature has plainly adopted the standard so expressed, viz.: that gas may not be produced, under existing conditions where the production thereof so greatly exceeds the market demand therefor, in quantities exceeding a reasonable proportion to the amount of oil produced, as the standard to be applied and beyond which the production is prohibited as being an unreasonable waste of natural gas.

"The standard so adopted by the legislature is, we think, not objectionable as being too vague or uncertain of application. The best mean ratio, or the amount of gas which bears a reasonable proportion to the amount of oil produced, may vary for each reservoir or deposit of oil, depending on the natural characteristics above mentioned, and may, and probably does, vary for each well drilled into the same

reservoir, depending on the location of the well and other factors. Therefore, because of the many and varying conditions peculiar to each reservoir and to each well, which will bear upon a determination of what is a reasonable proportion of gas to the amount of oil produced, it may be said that it would be impossible for the legislature to frame a measure based on ratios or percentages or definite proportions which would operate without discrimination, and that what is a reasonable proportion of gas to the amount of oil produced from each well or reservoir is a matter which may be ascertained to a fair degree of certainty in each individual case. The adoption, therefore, of such a measure seems to us to be within the scope of cases upholding other legislative enactments which have employed the so-called 'rule of reason.' Citation of authority is not necessary to support the statement that the standard of reason has been applied in many cases where certainty is less capable of measurement than in the present case, for instance, in statutes prohibiting unreasonable restraints of trade, the common law rule of a reasonable use of water by riparian owners, the rule of law regulating the duty of care, etc. Instances 'where a man's fate depends on his estimating rightly, that is, as the jury subsequently estimates it, some matter of degree,' are common. (See *Nash v. United States*, 229 U. S. 373, 377.)" [*People v. Associated Oil Co., supra*, Supp. p. 36.]

"It is insisted that this appellant is being penalized because it happened to strike the top of the structure where the gas pressure was greatest. In effect this is a contention that it should be permitted to exercise a right to the prejudice of a co-equal right possessed by its neighbors in the field. This contention cannot be sustained on well known principles of law with

reference to the exercise of rights in private property generally, but it also runs counter to adjudications on the subject of gas and oil development regulations by the highest court in the land. * * *

"Whether such wastage be reasonable or unreasonable is a question of fact and should be determined in view of the necessity of one landowner to make productive use of his parcel, in view of the equal right of the adjoining owners not to be deprived of correlative production from their parcels, and in view of the right of the public to prevent the waste of that which cannot be replaced. The preliminary injunction generally is supported by the facts presented to the court." [*People v. Associated Oil Co., supra.*, Supp. pp. 49-50.]

Natural gas occupies the same position in making the subsurface field productive of oil that water occupies in making the surface field fruitful with crops. There is the same right of many landowners in a common source of the fructifying supply. There is the same variation among the owners over the common structure in the quantity of the productive agency required to bring the values into possession. There is the same reason for pro rating the allowed use of gas energy to the landowner in the one case as in the other. In *Half Moon Bay Land Co. v. Cowell,* 173 Cal. 543, the court enumerated a long list of the factors properly to be considered in apportioning the waters of a stream among the riparian owners where there was not sufficient for the needs of all. In *Burr v. McClay Rancho Water Co.*, 154 Cal. 428, the court directed the judgment below to be modified so as to protect the owners of land over the subsurface percolating water who did not desire to make drafts against excessive drafts on the common supply by those desiring to make present use.

In *Katz v. Walkinshaw,* 141 Cal. 116, the court denounced the rule contended for, of the absolute right of each landowner to produce all the subterranean waters available from his wells on the ground that the rule would leave the field "open for exploitation to every man who covets the possessions of another or the water which sustains and preserves them." The analogy of these water cases to the law of oil and gas in subterranean structures is apparent, and they were applied in the opinion of the three California decisions construing the gas conservation statute now before this court.

Mr. Chief Justice White, speaking for this court, in *Red "C" Oil Mfg. Co. v. Board of Agriculture,* 222 U. S. 379, 394, says:

> "The legislative requirement was that the illuminating oils furnished in North Carolina should be safe, pure, and afford a satisfactory light, and it was left to the board of agriculture to determine what oils would measure up to these standards. We think a sufficient primary standard was established, and that the claim that legislative powers were delegated is untenable."

This definition construed as requiring an oil reasonably safe, reasonably pure, and an oil which will furnish a reasonably satisfactory light was here held to fully meet the tests where the question was not one of price fixing.

Other authorities in this court holding similar standards sufficient where men desirous of observing the law will have little difficulty in determining what is prohibited by it are *Omaechevarria v. Idaho,* 246 U. S. 348; *United States v. Alford,* 274 U. S. 264; *United States v. Wurzbach,* 280 U. S. 396; *Pierce Oil Co. v. Texas,* 212 U. S.

86; *Gundling v. Chicago,* 177 U. S. 183. Other cases in the Supreme Court of California following the same rule in respect to a primary legislative standard are *Ex parte McManus,* 151 Cal. 331, 335; *Bank of Italy v. Johnson,* 200 Cal. 1; *Dominguez Land Corporation v. Daugherty,* 196 Cal. 468; *People v. Globe Grain & Milling Co., supra.*

The statute as construed by the Supreme Court of the state leaves to the superior courts sitting in equity the determination of "unreasonable waste" as a question of fact in each case. [*People v. Associated Oil Co., supra,* Supp. 50.] We may, therefore, disregard remedies in the statute not involved in the action pending in the appellee equity court and not involved in the proceeding here. (*Ohio River & W. R. Co. v. Ditty,* 232 U. S. 576, 594.)

The final provisions of the statute (section 21) apply only to inspections of wells, fraudulent reports and acts of similar character. (*People v. McKean,* 76 Cal. App. 119, and cases cited.)

The persons engaged in the business regulated by this statute were fully advised of the evil to which the statute was directed, their attention being particularly called to both the waste of gas by release to the air and the underground waste by excessive gas-oil ratio, so that any one of them desiring to observe the law and taking into account the position of their particular properties in relation to neighboring properties and the gas-oil ratio of the wells they were operating could determine whether or not they were within the allowed limits of reasonable waste. The decision of the courts of last resort have so clarified the statutory primary standard as to solve the most lingering

doubt in the minds of those engaged in the business of producing oil and gas in California. It is not any uncertainty in the standard of unreasonable waste which has brought these appellants to this court but a desire not to conform the operation of their wells to a very clear and definite standard of conduct which is objectionable to them.

The statute is not being enforced by penalties and arrests but by "an action in equity where the enforcement * * * awaits the final determination of the court as to validity and scope." (*Smith v. Cahoon,* 283 U. S. ...., decided in this court May 25, 1931.) The question of "unreasonable waste" is one of fact to be found in each case by the trial court, "in view of the necessity of one landowner to make productive use of his parcel, in view of the equal right of the adjoining owners not to be deprived of correlative production from their parcels, and in view of the right of the public to prevent the waste of that which cannot be replaced." [*People v. Associated Oil Co., supra,* Supp. 50.]

> "The finding of *reasonableness,* like that of undue prejudice, is a determination of a fact by a tribunal informed by experience." *Virginian R. Co. v. United States,* 272 U. S. 658, 665.

The order denying the Writ of Prohibition should be affirmed.

Respectfully submitted,

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JAMES S. BENNETT,
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Attorneys for Appellees.

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CHARLES ELMORE CR

IN THE

SUPREME COURT

OF THE

UNITED STATES.

OCTOBER TERM, 1931.

No. 43.

Bandini Petroleum Company, a corporation; Commodore Petroleum Company, a corporation; Wilshire Oil Company, Inc., a corporation; Wilshire Annex Oil Company, a corporation, and Ambassador Petroleum Company, a corporation,

Appellants,

vs.

The Superior Court of the State of California, in and for the County of Los Angeles, and Honorable William Hazlett, as One of the Judges Thereof,

Appellees.

APPENDIX TO BRIEF ON MERITS BY APPELLEES.

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To refresh the judicial knowledge of the Court in respect to matters of common knowledge among those engaged in the production of oil and gas, we present herewith quotations from encyclopedic articles, government reports and technical discussions, and for purposes of illustration annex a cross section of a plane along the lines indicated on the map exhibit in the record.

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Attorney for Director of Natural Resources, State of California,
Attorneys for Appellees.

Day and Hill Report in 1912.

In the introduction to a chapter from Mineral Resources of the United States, calendar year 1912, prepared under the supervision of David T. Day by B. Hill, and published as a part of the report of the Department of the Interior, U. S. Geological Survey, the authors say:

"The natural gas industry has become one of the leading industries of this country, and to the United States belongs the credit of making natural gas a commercial product. It is the best of fuels, being cleaner, more convenient, and more efficient for almost any purpose than any other fuel. Were it possible to transport natural gas as coal, petroleum, or other fuels now in use are transported, it would be the leading fuel of the world and its value would probably exceed that of any other commodity. As it is, *enormous quantities are wasted annually, quantities too great even to be estimated*, and it is with the greatest difficulty that interest can be aroused to the importance of conserving this valuable fuel and preventing the exhaustion of the fields. Although steps have been taken in some localities to prevent waste, it still goes on."

Beal and Lewis Report in 1921.

In Bulletin 194, Department of the Interior, Petroleum Technology 61, published as a report of the Bureau of Mines in 1921, by Carl H. Beal and J. O. Lewis entitled Some Principles Governing the Production of Oil Wells:

"The factors governing the production of oil are extremely variable. Many of them can be studied and their influence on production can be determined, but the effect of others can only be estimated. Most of the factors are interrelated, and practically all are affected in some way by each other. Seldom can the effect of one be isolated completely and studied. In studying these factors, therefore, it is necessary to arrive at many conclusions by observing the action of oil properties or wells where one factor is stronger than the others. Some of the factors that control the oil content in a porous reservoir influence also the amount of oil that can be recovered from the reservoir and the rate at which it may be obtained. Therefore, the study of oil production includes the investigation of those factors (1) that control the total amount of oil in the reservoir, (2) that influence the amount of recoverable oil or the ultimate production, and (3) that control the rate at which the oil may be obtained—that is, the size of the wells and their rates of decline.

"The main influences in the production of a well may be classed as natural and artificial. The chief natural influences are the oil content of the reservoir rock; the resistance to the movement of oil through the reservoir rock; the expulsive forces; and the effectiveness of these

forces in expelling the oil from the reservoir rock. The chief artificial factors are the spacing of the wells, the operation of the wells, and the application of stimulative processes.

"Oil content is determined by the thickness, porosity, extent, and sometimes, the saturation of the oil sand. The factor of resistance depends chiefly upon the porosity, size of the sand grains, and the viscosity of the oil. The expulsive forces are the dissolved and the associated compressed gases, the direct water pressure and gravity. All these factors are interrelated as regards their influence on the ultimate production of a well, and they control the manner and rate of the flow of oil to the well. This paper discusses these factors and their influence on oil content, ultimate production and decline in production. (pp. 3-4.) * * *

"The main force that expels oil from a formation is the gas compressed and dissolved in or associated with the oil. Gravitation and direct water pressure occasionally play an important part in expulsion, but by no means as important a part as gas. (p. 12.) * * *

"When two wells are drilled near each other, the gas in the sand surrounding each well starts to force the oil toward the nearest well. This area of influence keeps extending from each well until the two areas touch, then interference sets in. The time elapsing before interference begins is governed by the factors of distance, pressure, and resistance to movement within the sand. With enough time one well might affect a whole field if the sand were continuous throughout. The greater the

pressure, the sooner will interference begin between wells of a given spacing, because the oil and gas will move with greater velocity. In an open sand containing light fluid oil the resistance to movements will be slight and interference will set in rapidly. Except for the thickness of the sand, the factors that make for large initial productions make likewise for rapid interference between wells. (p. 19.) * * *

"The proper utilization of gas as an expelling agent has already been discussed; but no mention has yet been made of *the device of partly 'closing in'* the well that is occasionally employed at large wells of high initial pressure. Producing in this manner through a 'bean,' or flow nipple, would appear to the layman to prevent production; as a matter of fact, however, the ultimate production can often be thus increased. *If such wells are permitted to flow to their utmost, the pressure in* the sand around the well is so greatly reduced that not only is *the valuable expelling agent wasted,* but the reduction of pressure in the sand allows rapid incursions of water and thereby cuts off bodies of oil which may never be recovered. The principles of 'stop-cocking' wells, used in early days in Pennsylvania, can probably be used with profit as advocated by Miles Quick and others. (pp. 21-22.)"

Swigart and Beecher Report in 1923.

In Bulletin 232, Department of the Interior, Manual for Oil and Gas Operations, prepared by T. E. Swigart and C. E. Beecher, and published in 1923, the authors say:

"The conservation of natural resources, therefore, can not be interpreted as nonuse, but as *use with minimum waste*. A greater gift to posterity than undeveloped supplies of raw minerals is the advanced civilization made possible by the thoughtful use of a necessary portion of these minerals.

"In the United States much of the mineral wealth is privately owned. Unfortunately all these owners have not learned the lesson of modern civilization—that private ownership is in reality public trust and that the owner's right to do as he pleases, even to squander natural resources, can not and will not be tolerated indefinitely by society.

"No one will deny that the oil and gas industry has been *wastefully operated*. Much of the *waste probably could have been avoided*, although critics must concede that the hazardous nature of the industry and lack of operating experience that could be gained only by time are partly responsible. Little good will come of deploring past errors, but great good may result from studying the *causes of these wastes* and their future prevention.

"The American petroleum industry is now in its sixty-fourth year. During this time recovery methods have been almost revolutionized. When conducted properly the best practice of today permits little waste of oil and gas." (pp. 2-3.)

"If more gas than is needed is used for producing oil, a *direct waste of gas* and an indirect waste of oil result,

as so-called 'dead oil' that can never be recovered by ordinary producing methods is left underground in the oil sand. To recover this oil would necessitate costly artificial methods which some day may include mining of the sands. Lewis has estimated that ordinarily from 80 to 90 per cent of the original oil in an oil sand is left underground when a well is abandoned. If, by new methods of controlling the flow of gas, this percentage could be reduced by 10 or 20 per cent (and it seems reasonable to believe that even greater reductions may be possible), the benefits from increased oil recovery can not be overlooked. For this reason, if an operator permits more gas to flow into the well than is needed to bring the oil into the hole, he is wasting a commodity that the Government is anxious to conserve.

"Swigart and Bopp found that when handled in different ways, the pumping wells upon which they experimented would produce varying amounts of gas with the oil. A computed factor, termed the 'gas factor of oil production,' which in reality was the number of cubic feet of gas produced with a barrel of oil, was used as the measure of efficiency in producing oil in those experiments. *Thus, the smaller the gas factor of oil production,* the smaller would be the quantity of gas used in producing each barrel of oil, the slower the decline in rock pressure and depletion of the gas, and, consequently, *the greater the ultimate quantity of oil that each well will produce.* (p. 89.) * * *

"The number of cubic feet of gas produced with each barrel of oil is the true measure of efficiency of production of a well, because this factor takes into account both oil and gas productions. *The most efficient well is the one operated so as to produce the minimum amount of gas per barrel of oil."* (p. 92.)

Swigart and Bopp Report in 1924.

Technical Paper 322, Department of the Interior, published in 1924, prepared by T. E. Swigart and C. R. Bopp, under the title of Experiments in the Use of Back Pressures on Oil Wells:

"Few accurate records of the oil and gas production of wells have been kept by oil companies and the average amount of gas that might be expected to accompany each barrel of oil under fairly good operating conditions is not known for all properties. (p. 42.) * * *

"In the new Santa Fe Springs field, Southern California, one 2,500-barrel flowing well produced 684 cubic feet of gas per barrel and another, 3,100-barrel flowing well produced 943 cubic feet per barrel of oil. The flowing of these wells was restricted by chokers (flow nipples). (p. 43.) * * *

"Engineers have agreed that both absorbed and free gas, if free gas is present, assist oil to migrate from outlying parts of a reservoir to a well. The greater the rock pressure and consequently the greater the amount of natural gas in a given reservoir, the greater will be the ultimate recovery of oil from a well. Experience has shown that relatively small amounts of oil are recovered from a well after its gas pressure has declined very low.

"Methods that permit oil to be extracted from natural underground reservoirs with a *minimum amount of gas per unit of oil will insure the greatest ultimate recovery of oil.* Operating methods that permit or encourage the *escape of more gas* than the minimum amount required to bring each unit of oil into the hole *will lessen the amount of oil that may be recovered ultimately.*" (p. 58.)

Hopkins and Backus Report in 1927.

Department of Commerce publications, Mineral Resources of the United States, 1927, Part II, pages 129-137, under which subject Natural Gas by G. R. Hopkins and H. Backus:

"The relative rank of the large natural gas producing states was materially changed in 1927. Oklahoma retained first place, Texas advanced from fourth to second place, and Louisiana from fifth to fourth. *California dropped from second to third place and displaced West Virginia which dropped to fifth place.* The output in Oklahoma increased 14 per cent in 1927, chiefly as the result of production incidental to the intensive drilling for oil at Seminole. Texas showed the largest increase in output—45 per cent—of all the major gas-producing states; as in Oklahoma, this increase was due to oil development, particularly that in the Panhandle.

"The total consumption of natural gas (including residue gas from natural gasoline plants) by industrial users in 1927 amount to 1,149,208,000,000 cubic feet, an increase over 1926 of 12 per cent; this total was divided about equally between field use (that is, for drilling, pumping, and operating gasoline recovery plants) and other industrial uses (including gas burned in making carbon black and gas used by manufacturing establishments)." (pp. 129-130.)

Reprint From Report of H. C. Miller on Function of Natural Gas in the Production of Oil For the U. S. Bureau of Mines and the American Petroleum Institute, 1929.

Reservoirs of Oil and Gas.

(18) Reservoirs yielding oil and gas are generally found in sedimentary rocks. In a few recorded instances oil has been found in igneous and crystalline rocks, though generally not in sufficient amounts to be important commercially. Most of the oil produced in the United States is found in porous, sandy strata varying in texture from fine-grained sandstone to conglomerate. These rocks are termed "sands." Considerable oil is also found in limestone, and a small amount is produced from fissures in shale.

The oil sands of California are loosely cemented sandstones and soft unconsolidated sands consisting of irregular and angular shaped sand grains. In Oklahoma the greater part of the oil is produced from consolidated sandstones which vary in texture from soft and friable, to hard and firm. In the Texas Panhandle oil fields much production comes from granite wash—a conglomerate composed of granite fragments that have been eroded from granite ridges and deposited along their slopes—and from overlying dolomite. Most of the oil produced in Pennsylvania and West Virginia comes from hard, fine-grained sandstones and compact conglomerates.

(19) Core samples have shown that most oil fields in California, unlike those of the Mid-Continent and Eastern districts, comprise a series of oil sands, sandy shales that may bear oil, and shales. These strata may have a thick-

ness of a few feet to as much as 2,000 or 3,000 feet. Frequently, wells in the California fields drain a zone several hundred or more feet in thickness.

Not only are the productive zones of varying thickness, but their porosities differ and sometimes are as high as almost 40 per cent. In contrast to this, the porosity of some of the dense, fine-grained sandstones from which oil is produced in Pennsylvania is as low as 7.5 per cent.

Each producing sand in the average deep well in California may have a different texture, and the degree of saturation is seldom the same in any two producing horizons. Formation pressures are not the same in the various producing zones; because of the great difference in the depth of the individual sands in different wells, caused by the pronounced dip of the formations, each sand may even have different pressures in various parts of the same field.

The characteristics of the oil and gas found in the various producing sands in a California well and the relative proportions of gas and oil generally differ. Even the gravity of the oil in the upper and lower sands in single wells shows a considerable range. In California, also, lenticular sands and shales are common, and although some of these might be isolated from water, nearly all the oil sands are flanked by edge water.

In general, oil reservoirs may be divided into three types, which differ as to nature and origin and which have important bearing on the manner in which the oil is yielded to wells drilled into them.

(20) Probably the most common type of reservoir, which may be called the *pore* type, is that in which the oil is

contained in minute pores in the reservoir rock. Sandstone or sand is the most common reservoir of the pore type. Limestone and dolomite reservoirs are of the pore type in some instances.

Other reservoirs are of the *cavernous* type, in which the porosity is in the form of larger or smaller caverns or solution channels such as are very commonly formed in soluble rocks like limestone, dolomite, or salt. Limestones which have been exposed to erosion and later buried have produced many oil reservoirs of the cavernous type. The solution channels may vary from minute channels honeycombing the rock to caverns large enough to permit drilling tools to drop several feet when they are struck.

The third or *fissure* type of reservoir is that in which the porosity is due to open fissures in what may otherwise be impervious rocks, such as shale or impervious limestone.

In their effect on the behavior of a well drilled into them, the reservoirs of the cavernous type and those of the fissure type may be grouped together, because in both the openings are relatively large, and the flow of oil through them is relatively free and is not subjected to serious interference by the action of capillarity.

Status of Oil in Reservoir Rocks.

Oil exists in its undisturbed reservoir rocks under a pressure which generally corresponds rather closely with that of a column of water of a height equal to the depth of the reservoir below the surface. This pressure is undoubtedly hydrostatic. In some instances the pressure

may be more or less than hydrostatic, but these instances are believed to be due to special conditions.

The relations of oil, gas, and water in various reservoirs differ widely and have the greatest influence on the manner in which the oil is produced when the reservoirs are tapped. In some reservoirs there is little gas and the oil is backed up by water in hydrostatic connection with it, so that as the oil is produced at the wells the water follows up in its place. Such wells yield their oil by steady flow, which may continue at a fairly uniform rate for a considerable time, or even until most of the oil has been produced. The water acts as a natural water drive, and is thought in many cases, to cause a high percentage extraction of the oil.

(21) In some reservoirs the oil pool is not backed by water in hydrostatic connection with it, so that only the expansive force of the gas associated with or dissolved in the oil is available to force it out to the well. The recovery of oil by natural means from such a reservoir depends mainly upon the action of the expanding gas in driving oil to the well and in carrying it to the well in the form of films surrounding the gas bubbles. When the gas energy has been exhausted, the oil still remaining in the sand, which must necessarily be a large proportion of the original amount remains irrecoverable except by other than natural means. When a reservoir of this type at great depth and under correspondingly great pressure is first tapped, the effect of the expanding gas is almost like that of an explosion, and spectacular gusher wells are the result.

In some instances the oil in the reservoirs is backed by water in hydrostatic connection with it and also contains free and dissolved gas under high pressure. In such cases the results of tapping the reservoir combine the spectacular gusher production of the gas expansion type with the sustained later production characteristic of hydrostatic water drive.

The type of reservoir also exerts great and characteristic effects on the behavior of wells tapping it. Reservoirs of the pore type yield wells of relatively moderate initial production, gradual decline, and long life—results of the difficulty of movement of the oil through the minute pores in which it is held in the reservoir rock. Reservoirs of the cavernous type yield wells of high initial production and characteristically rapid decline. Since the caverns or solution channels in which the oil occurs are large enough to permit free movement, the oil is produced rapidly and exhausted rapidly. (22) Interference of wells is common; early wells in the field have enormous advantages over later ones and spotty distribution of large and small wells is also common. Shooting of small wells has been known to result in large production caused by breaking of the shot into channels not tapped by the well bore.

Fields producing from limestone or dolomite, from salt dome cap rock, and from fissures in shale commonly show the characteristics outlined above.

In planning methods of operation to secure the greatest percentage of oil extraction from a reservoir and methods of recovering oil from depleted fields, the nature of the reservoir—whether of the pore, cavernous, or fissure type

—and the nature of the force driving the oil to the wells—whether gas expansion alone, water drive alone or a combination of the two—are vitally important considerations. Methods which are effective with one type of reservoir or of driving agent are likely to be entirely inadequate under other reservoir conditions.

Capacity of Sands for Storing Oil.

Porosity is the ration of effective pore space to the volume of sand and therefore usually represents the capacity of sand for storing oil. According to Melcher[3] of the U. S. Geological Survey, "the pore space can be divided into two kinds, the total pore space and the effective pore space. The total pore space is the total interstitial space and includes not only the communicating pores, but any isolated pores that may exist. The *effective pore space,* on the other hand, is relative, depending on such factors as the consitution of the liquid, the size of the pores, the material of the rock, temperature, pressure, and other conditions."

(23) Production men are interested mainly in the effective pore space of reservoir rocks, since oil trapped in isolated pores can rarely, if ever, be recovered.

Oil sand composed of spherical grains of uniform size will have more pore space between grains than one composed of grains of many sizes and irregular shapes. Where the grains are not of uniform size, the smaller grains may fill the interstices between the larger grains and reduce the porosity. It is a mistake to assume that

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[3] Melcher, A. F., Determination of Pore Space of Oil and Gas Sands: Trans. A. I. M. E., vol. 65, p. 469, 1921.

because a sand has high porosity it will yield its oil readily and ultimate recovery will be high. The size and arrangement of the pore spaces have a marked influence on the rate of movement of oil through the sand. Oil will flow more readily in sands with large intercommunicating pore spaces than in so-called "tight sands" where the pore spaces may be so small that adhesion and capillary attraction retard the movement of the oil, even though the porosity may be greater. If the explusive forces in a low-porosity sand are high and the sand is of coarse grain with the pore spaces in communication, ultimate production may be relatively higher than from a high-porosity sand. On the other hand, when the oil is of low gravity and high viscosity, relatively higher recoveries will be had from sands of high porosity than from those in which the volume of the pore space is less.

Movement of Gas and Oil Through Reservoir Rocks.

(26) A reservoir of porous formations containing oil and gas has definite dimensions and is charged with a given amount of oil and gas under a certain pressure before equilibrium within the reservoir is disturbed either by natural causes or drilling. No appreciable amounts of oil and gas are added to a reservoir by natural means during the productive life of a field, nor is there an increase in the original reservoir pressure due to natural causes.

In their original state, in an undrilled or virgin oil field, the several hydrocarbons that comprise natural gas under surface conditions of temperature and pressure may be considered as existing in four separate phases; (1) dissolved gas in the oil, (2) free gas mingled in the pore

spaces with the oil, or collected above it in structurally high parts of the reservoir formation, (3) gas in the liquid phase, and (4) absorbed gas.

Since the reservoir pressure in many oil fields is well above the critical pressure (see p. 240) of some of the constituents of natural gas, it is certain that some hydrocarbons that are gases at atmospheric pressure and temperature are liquids in the reservoir. Natural gas is a mixture of methane and heavier hydrocarbons, some of which liquefy at the pressures found in oil structures. Above their critical temperature, however, gases cannot be liquefied by pressure. Methane, for instance, could not be liquefied by any pressure in a well because the temperature in wells is never as low as its critical temperature, and ethane can be liquefied only where the temperature is below 95° F. All other gases in natural gas may easily exist as liquids in reservoir formations.

Table 2 gives the critical temperatures and pressures of a few of the methane series of hydrocarbons found in petroleum.

The principal source of inherent energy contained in an oil reservoir during its early life is the expansive force of the gas associated with the oil. Oil men agree, and laboratory and field experiments have definitely established the fact, that most oil fields have become depleted not on account of the exhaustion of the oil in the reservoir, but because of the depletion of the gas pressure. Laboratory experiments,

TABLE 2—CRITICAL TEMPERATURES AND PRESSURES OF (27) VARIOUS HYDROCARBON GASES.*

	Critical Temperatures F.	Critical Pressures, pounds per square inch
Methane	—139.9	736.5
Ethane	95.0	665.8
Propane	206.6	662.8
Butane	307.4	522.0
Pentane	387.0	486.6
Hexane	454.1	441.9
Heptane	512.3	394.8
Octane	565.5	371.2

followed by experiments in various oil fields and especially in areas where rejuvenation methods are being applied, substantiate the fact that ordinarily the recovery of oil from sands through the propulsive force of the gas dissolved in the oil has been on the average only 15 to 20 per cent of the oil originally contained in the sand. Cores from depleted oil sands in the Bradford field in Pennsylvania showed that at least 64 per cent of the original oil was retained in the sand after ordinary pumping methods had been followed by a water drive. Data on the Pechelbronn mine in Alsace, France, indicate that only 16.7 per cent of the original oil was secured by production through oil wells by ordinary pumping methods.

(28) Experienced oil men and engineers concur that modern improved production methods, as for example the holding of back pressure on flowing and pumping wells, and the scientific production of oil result in the recovery of a

*Day, David T., Handbook of the Petroleum Industry: Vol. I, John Wiley & Sons, Inc., 1922, p. 730.

greater percentage of oil than was possible by former less efficient methods. Certain controlled experiments[6] on oil recovery conducted by engineers of the Bureau of Mines show 24 to 33 per cent recovery of oil from sand for 500 pounds initial gas pressure and a recovery varying from 30 to 43 per cent when the initial gas pressure was 1,000 pounds per square inch. The results of these experiments "indicate that the percentage recoveries of oil originally occuring in sands at different initial gas pressures may be somewhat higher than has been supposed by some engineers."

It is recognized that water associated with oil may materially aid in the drainage of oil from reservoir sands. Water is especially active as a propulsive force when the pore spaces in the sand are of capillary size since water has about three times as much force of surface tension as oil. Edge water, motivated by hydrostatic pressure, acts as a natural water drive in some fields. The effect of edge water is especially noticeable in certain fields where the gas pressure has been dissipated and the drainage of oil to wells ahead of the water "wave" continues at a rate which make production profitable.

Edge water, if allowed to encroach too rapidly, may bypass the less permeable lenses filled with oil. However, where its rate of encroachment is controlled by back pressure or other production methods, the effect of edge water may be advantageous in flushing the sands and maintaining a pressure on the oil in the sands.

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[6] Mills, R. Van A., Chalmers, Joseph, and Desmond, D. D., Oil Recovery Investigations of the Petroleum Experiment Station of the U. S. Bureau of Mines: A. I. M. E. Technical Paper 144, p. 26, 1926.

(29) Top water, or bottom water, in oil reservoirs is usually considered detrimental to the efficient recovery of oil from reservoir sands. The effect of such waters in driving oil away from wells and entrapping it in the tighter and less permeable sands is due to the lower viscosity and greater surface tension of the water and to the selective permeability of the sands which results in greater freedom of movement of water than oil. It is believed that top and bottom waters enter the channels already open or partially depleted of oil and isolate the less permeable sands, sealing quantities of oil in these lenses and forever preventing its recovery.

Once a sand or portion of a sand becomes flooded, it is desirable to exclude it from among those sands being produced, since the greater mobility of the water will soon enable it to drown out the oil in other sands unless they are under much higher pressure than the water.

The force of gravity is a factor of some importance in the recovery of oil in fields where the producing strata are thick or steeply inclined, but at best it is a comparatively slow-acting force. During the early life of fields in the United States it is improbable that gravitation is of much importance as a factor in the drainage of oil from sands, because the dips of most of the oil-producing formations are relatively low and the sands are irregular in texture and bedding.

Gas pressure, water pressure, and gravity are usually present in the same reservoir.

(37) There is no doubt in the minds of oil men and engineers that the predominant expulsive force that drives oil to wells is the energy stored in the compressed gas

absorbed in or associated with the oil. Admitting that natural gas is usually the most important factor in oil recovery, its control in order to cause it to do the most work in driving oil from the sand to the well is of utmost importance; every possible means should be taken to conserve the gas pressure and prevent its dissipation. Certainly the operator should be able to control the efficiency of the work of natural gas to a greater extent and with far greater effect on the economic ultimate recovery of oil from the sand than he can the efficiency of water and gravity.

Resistance to Flow of Oil Through Sands.

As soon as a well is drilled in and oil starts to flow from the sand, the condition in the reservoir undergoes a change. The reduction in pressure permits the gas to come out of solution in the form of minute bubbles, and as the pressure is reduced further, the expansion of these bubbles forces part of the oil through the sand to the well. However, the following and other factors tend to retard the movement of oil toward the well: (a) The increasing viscosity resulting when gas comes out of solution in oil, (b) the surface tension of the oil film on gas bubbles, (c) the distortion of these bubbles in passing through the pore space interstices, and (d) adhesion. At (38) any given time during the life of the well, a certain amount of energy is required to overcome these resistances and cause the oil to flow to the well. The expenditure of original gas in excess of that required results in a reduced ultimate oil recovery, or requires that a proportionally larger amount of energy be supplied, unless replaced by artificial means, to produce maximum ultimate recovery.

It is generally agreed by production engineers that the amount of oil recovered from a given reservoir is inversely proportional to the recovery gas-oil ratio. The problem of the operator then is to use efficiently the store of natural-gas energy, making each foot of gas do the maximum amount of work in moving the oil through the formations and to the wells.

The forces resisting the flow of oil toward wells may be divided into two classes—internal and external. Internal resistances are: (a) The result of the viscosity of the oil itself, increased doubtless in some cases by the presence of finely divided shale particles or colloidal silica which often manifest themselves later as emulsifying agents, and (b) the phenomena known as the Jamin effect, wherein the resistance is increased by the surface tension of the oil film around the gas bubble. To force the bubble through an aperture smaller than itself, it must be distorted from a true sphere; such distortion is resisted by the surface tension of the oil film, and work must be done to overcome this resistance.

External resistance to flow is dependent on the character of the sand, its fineness, uniformity, sharpness, clearness of grain faces, and presence or absence of cementing material all of which affect the shape, size, and smoothness of the channels through which the oil must move. The external resistance varies with the rapidity at which the oil column is moving at some power, other than the first power, of the velocity. The rate of production therefore seriously affects the amount of energy consumed per barrel of oil in overcoming external resistance to flow, and likewise affects the amount of gas which must be expanded to furnish this energy.

(39) Adhesion of the oil to the walls of the sand channels, when such channels are sufficiently small, gives rise to capillary resistance. The exact magnitude and importance of capillary resistance under ordinary subsurface conditions are difficult even to estimate. That it is a resistance at least worthy of consideration and study is unquestioned. It is believed that capillarity is an important factor in preventing the separation of oil and gas in a porous stratum while that stratum is in a static condition. Furthermore, the sealing of the pore spaces with oil by capillary action may prevent by-passing of the gas when conditions are no longer static but dynamic.

Factors Affecting Changes in Resistance to Flow.

The effect of changing underground conditions on the several resistances to flow is worthy of consideration. Changes which, among others, are important are those of pressure, temperature, and rate of flow. Reduction in pressure allows the free gas, if any, to expand, liquefied hydrocarbons to change from the liquid to the vapor state, and by reducing the solubility of gas in the oil causes some of the gas to come out of solution. All of these changes increase the size and number of gas bubbles in the oil; increase the Jamin effect, both by multiplying the number of bubbles and intensifying the surface tension of the oil; and increase the viscosity of the oil through the escape of dissolved gas. Each of these separate effects tends to add to the amount of work necessary to move a barrel of oil a given distance. Therefore, it is safe to state that the higher the average pressure which can be kept effective on the formation, the more readily the oil will move toward the well.

Decrease of underground temperatures, which might result from sudden release of pressure on the sand and the consequent rapid expansion of gas, is commonly accepted as being relatively unimportant in its effect on (40) resistance to flow. Lowered temperature would result in greater solubility of gas, which would tend to lower the viscosity and surface tension; this effect, however, would be offset by the direct temperature effect on the viscosity and surface tension, both of which are increased at lower temperatures. Certain oils have the viscosity increased greatly by lowered temperatures, and others precipitate waxes or waxlike solids which increase production difficulties greatly. Any change in operating methods that would result in lowered underground temperatures is therefore to be avoided.

Changes in the rate of flow affect the efficiency of production by increasing the energy consumed in overcoming internal and external resistance to movement of oil through the sands. A rate of flow is therefore desired which will balance efficient use of the gas energy against the operator's desire for high productivity of wells.

Effect of Dissolved Gas Upon the Viscosity and Surface Tension of Crude Oil.

The role that natural gas plays in the production of oil is twofold; first, natural gas in solution in petroleum imparts desirable physical properties to the crude for its efficient migration, and second, the force of expansion of natural gas, as discussed in the section on the movement of gas and oil through reservoir sands, acts as a propellant in moving oil through reservoir sands to the well which is the point of lowest pressure.

From laboratory experiments it is found that gas in solution in crude oil decreases the viscosity and surface tension, thus imparting physical properties to the oil which are conducive to the utilization of less energy in causing it to flow. It is believed that the results found in the laboratory have their application to conditions as they exist in the reservoir sands. A knowledge of the results of these laboratory tests is essential, therefore, to an understanding of the desirable physical effects that (41) natural gas in solution has on petroleum.

Reduction of Viscosity by Dissolved Gas.

The amount of gas dissolved in a crude oil is directly proportional to the gas pressure. Beecher and Parkhurst[7] found that by saturating a given crude with natural gas at 500 pounds pressure per square inch and 70° F., the viscosity was decreased 50 per cent. It is therefore within the bounds of reason to assume that at a pressure of 1,800 pounds per square inch, corresponding to a depth of about 4,100 feet, enough gas may be dissolved in the crude in an oil reservoir to reduce the viscosity to that of kerosene.

Efficient Use of Natural-Gas Energy.

(44) As has been shown, work is necessary to move oil against the combined effects of frictional resistance of reservoir formation material, viscosity of oil, and gas-bubble resistance. Since the principal source of energy to perform this work is the expansion of the gas that ac-

[7] Beecher, C. E., and Parkhurst, I. P., Effect of Dissolved Gas Upon Viscosity and Surface Tension of Crude Oil: A. I. M. E., Petroleum Development and Technology in 1926, p. 51.

companies the oil, the amount of gas produced with a barrel of oil has come to be considered as a measure of the amount of work being done underground; the efficiency of wells and properties, therefore, are being compared on the basis of their gas-oil ratios or quantities of gas produced per barrel of oil. Such a comparison is fair only so long as the reservoir pressure conditions are the same, since the amount of work done varies not simply with the quantity of gas, but as the product of this quantity and the reduction in pressure; or, by the number of times the gas has expanded in passing from the formation pressure to its final pressure where it discharges its load of oil into the casing.

(45) Pressure is as fundamental as volume. Obviously, the force exerted by 1,000 cubic feet of gas under, say, 100 pounds per square inch pressure is far less than the force exerted by the same quantity of gas under 1,000 pounds per square inch pressure. The fundamental factor is the combination of pressure and volume, which together equal the force exerted by the gas. It is this force that is important. In comparing producing methods at the same well, the volume alone can be used as the index, but comparison of recovery gas-oil ratios between fields or even wells in different zones or areas in the same field can be made only by taking into consideration the differences in reservoir pressures, depths, and other factors that affect the amount of work accomplished by 1 cubic foot of gas.

(47) For every well there is a critical differential pressure and a critical velocity induced by this pressure which will result in the most economical rate of flow of oil to the well. The problem for the operator is to control the back pressure on each well so that the gas escaping from

the reservoir sands will carry the maximum amount of oil to the well. Experience has shown that it is difficult generally to get operators to hold anywhere near enough back pressure on their wells for maximum utilization of formation gas energy. Unless the gas is used efficiently in moving oil to the well, ultimate oil recovery from the reservoir sands will be reduced proportionally.

From the preceding discussion it is evident that the most efficient method of gas utilization is one where the gas moves with the oil so that the gas-oil ratio approaches as nearly as possible the amount of gas dissolved in the oil at the existing reservoir pressure; also, that the most efficient theoretical differential in pressure would be the one which gives this theoretical low gas-oil ratio.

(232) When gases and volatile hydrocarbons are removed from the solution, the physical properties of the latter are changed. The resulting liquid has greater density, greater viscosity, and greater surface tension than when the light hydrocarbons were present in larger proportion. The extent of these changes will depend, of course, upon the amounts removed from solution, which in turn depend upon the decrease of pressure.

In the formation below the surface of the earth, the petroleum is found dispersed, throughout the small interstices of porous "oil sands" saturated with gas under pressure which may be as high as 100 atmospheres or even higher. When a well is drilled into this formation and fluid is allowed to flow out, the pressure at the intake of the well is decreased. This immediately causes a pressure gradient in the formation which tends to force fluids toward the well intake where the pressure is lower.

Consider what will happen as this process is continued. The pressure throughout the formation gradually decreases. The possible pressure gradient from the remote parts of the formation toward the well is decreased, and therefore the available energy for driving the fluids to the well is lowered. The lowered pressure allows dissolved gas to separate from the liquid petroleum in proportion to the decrease of pressure, and the gas forms minute bubbles in the oil. These bubbles grow in size and often join to form larger ones. The oil, to reach the well, must flow through fine capillary pores between the sand grains. The presence of these gas bubbles, which offer considerable resistance to the distortion necessary to force them through the capillaries, offers a serious impediment to the desired flow of oil.

Another disadvantage of the release of dissolved gas lies in the resulting increase in viscosity of the oil. Increased viscosity has the effect of adding greatly to the difficulty of flow toward the well, requiring a greater pressure gradient for a given flow rate and thus absorbing more of the available energy than is desirable.

(233) Still another troublesome result of gas coming out of solution from the oil is the increase in surface tension of the liquid and the greater tendency to hold tight to the capillary sand pores. This condition involves the expenditure of more energy to remove the oil from the sand and increases the proportion of the oil which cannot be economically recovered. This unrecovered fraction is large at best.

As is easily seen, the release of dissolved gas in the formation is unfortunate and should be avoided as much

as is feasible. Some decrease in pressure in the formation is necessary to cause oil to flow to the well inlet. There are two ways of getting a given flow rate to the well: First, use a low pressure gradient, thus holding gas in solution and taking advantage of lower viscosity and adhesion and the presence of fewer and smaller gas bubbles to counterbalance the lower energy availability; second, let the pressure at the well inlet drop low, allowing greater quantities of gas to escape and opposing much greater resistance to flow but relying upon the greater pressure gradient to supply the additional energy required. It is not difficult to decide which of these two procedures will give the largest ultimate yield of oil with the least expenditure of energy from the formation. Unfortunately, the second method has been very commonly used.

(246) **Function of Gas in the Reservoir.**

(a) Gas associated with or in contact with the oil in reservoir rocks provides the propulsive energy which moves oil to the wells. All petroleum engineers are agreed that where gas provides this energy the exhaustion of oil from oil-bearing formations is due more to depletion of the gas than to actual exhaustion of oil. Water and gravity also play a part in oil recovery, but gas usually provides the main force which moves oil through the reservoir rocks to the wells. Because of the influence of gas in the production of oil, and by reason of its importance, the common supply should be controlled in the common interest.

(b) The amount of gas associated with a barrel of oil depends largely upon pressure. Gas is commonly believed to exist in four phases in the reservoir:

(1) As free gas in higher portions of the structure.

(2) As a liquid where pressure is sufficiently high.

(3) In solution in the heavier liquid hydrocarbons present.

(4) Absorbed at the interfacial surfaces.

(c) Natural gas in solution lowers the viscosity and surface tension of the oil in the reservoir, thereby reducing the resistance to movement of oil in the sand toward the well. The volume of gas held in solution in oil is in direct proportion to the pressure, if other conditions (247) remain constant. Holding as much of the gas in solution in the oil as possible will therefore keep the oil more fluid, and through lowered surface tension and the lessened growth of bubbles will thereby reduce that resistance to flow which is known as the Jamin effect.

(d) Temperature measurements, where available, indicate that the production of oil and gas sometimes reduces the original formation temperature. Such temperature changes as do occur probably are localized to the immediate vicinity of the well, possibly almost wholly within the well.

(e) Gas injection compensates to a degree for some of the harmful effects of producing oil with high gas-oil ratios, but it cannot reproduce original conditions in the reservoir. The factors considered of greatest importance are:

1. Time.
2. Lack of agitation.
3. Slow rate of diffusion.
4. Inability to replace absorbed gas.

5. Change in character of gas returned due to extraction of gasoline.
6. Relative small number of injection wells as compared to producing wells.
7. Water encroachment.
8. Differential permeability (the inability to direct the gas to the particular sand desired).

(f) *Repressuring with gases other than the original gas. The use of air is considered undesirable where the oil is asphaltic, or contains many unsaturated compounds which are readily oxidizable.* Air is less soluble and does not reduce the viscosity or surface tension as does natural gas. Corrosion of casing and tubing, particularly if the oil be high in sulfur, is almost sure to result from the use of air as a substitute for gas. Also, compressed air vitiates the gas still remaining in the reservoir rocks, and as the supply of gas for fuel is usually low in districts where air is used for repressuring, the *returned air-gas mixture is often explosive and unfit for fuel purposes.*

(248) (g) There appears to be a lack of uniformity of opinion as to the character of flow in the sands. Data and opinions indicate that there may be viscous flow, turbulent flow, or a progressive mixture of the two, depending to some extent upon time and relative position in the reservoir. Other factors which are considered important in their influence upon the type of flow are the character of the oil, the amount of gas present, the pressure, and the size of the pore spaces through which the oil moves.

Methods for Increasing the Recovery From Oil Sands. Lewis, 1917. Petroleum Tech. 37, Bulletin 148, Bureau of Mines.

How Oil Is Retained in the Sand.

(21) The expulsion of the oil from the sand is retarded and opposed by viscosity, capillarity, adhesion, and frictional resistance in the sand. It has been shown that viscosity is greatest for heavy oils and at low temperatures, and how the other factors are most important in fine sands of low porosity, especially if thinly or irregularly bedded. Frictional resistance is further increased by the sands being clogged by the deposition of waxy materials from oils of paraffin base or by the accumulation of silty materials or "floating sand" in the pores of the sands. A portion of the energy released from the expanding gas is used up in overcoming the resistance from these causes, but in addition much of the energy is wasted, owing to the escape of gas without doing work. There is a marked tendency for the gas to slip by the oil through the larger pores of the sand and through parts of the sand body offering least resistance without expending much energy in actually moving oil, this tendency increasing enormously with the removal of the oil, as shown by the experiment cited previously.

It is likely that in sands where there is the greatest opposition to the expulsion of oil—that is, in fine sands of low porosity and with heavy oils—there will be rela-

tively less waste of energy, for the gas will not be so apt to slip through the sand without moving oil. This probably explains why tight sands and heavy oils usually give wells that maintain their productions very steadily. But the more irregular the texture and the character and proportion of contents of a sand body the greater will be the waste of energy which is essentially like the "by-passing" of air in the Smith-Dunn or Marietta process that has proved to be one of the chief difficulties to overcome in the use of compressed air.

The proportion of oil recovered from an oil sand may be said to represent a balance of the energy originally stored in the oil sand with the waste of energy and the opposition to the expulsion of the oil. This might be termed the "efficiency of expulsion," and will depend not only on the natural conditions but also upon the manner in which the producer operates his wells. While the operator can not control the original conditions of energy and resistance in the sand, he can partly control the efficiency of expulsion. As it is the energy contained in the compressed and absorbed gas rather than the oil that is exhausted, it is but logical to judge the efficiency of a producing method largely by the relative quantities of gas produced with each barrel of oil. If by a change in method the producer lessens the proportion of gas with each barrel of oil, he should increase the total recovery of oil correspondingly, even if the rate of production is temporarily reduced somewhat.

Capacities of Oil Sands.

(28) From the evidence previously submitted the following figures on the porosities of oil sands are believed to be reasonable. The porosities of oil sands are much greater than the uninformed would suspect from a casual inspection of specimens, whereas the usual ways of testing the porosity lead to underestimates. There is little published information on the porosities of sands actually productive of gas or oil, but there is no reason to believe that they are less than for other sands and standstones. Indeed, as pointed out previously, the porosities of the oil-producing sandstones of the Mid-Continent and eastern fields must be greater than the figures on the building sandstones indicate. In any event, the recovery of gas shows that the estimated capacities of the oil sands, as given in the following table, can not be in gross error.

ESTIMATED AVERAGE CAPACITIES OF OIL SANDS.

	Estimated average porosity, per cent.	Capacity per acre-foot, barrels.
Appalachian field	12½	970
Illinois and Mid-Continent fields	17½	1,358
California fields	25	1,940

Actual Recovery From Oil and Gas Sands.

According to the United States Geological Survey,[a] 3,335,457,140 barrels of oil have been marketed from 329,186 oil wells in the United States up to the beginning of 1915. During 1914, 265,762,535 barrels were mar-

[a] Northrup, J. D., Petroleum; Mineral Resources U. S. for 1914, U. S. Geol. Survey, 1915, p. 889.

keted from 179,129 oil wells. It is estimated that the average well drained about 6 acres of oil land, the total (29) area being about 2,000,000 acres. The future production for the wells producing in 1914 is estimated to be not more than 1,400,000,000 barrels, making a total production of approximately 4,700,000,000 barrels, or approximately 2,350 barrels per acre, which is hardly enough to saturate an oil sand 2 feet thick of average porosity.

Statistics by the United States Geological Survey[a] show that 591,866,733,000 cubic feet of natural gas was produced and used in the United States in 1914, which does not include the enormous wastage.

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[a] Northrup, J.D., Natural Gas; Mineral Resources U. S. for 1914, U. S. Geol. Survey, 1915, p. 749.

Gas-Lift Methods of Flowing Oil Wells (California Practice). Lewis, 1930. U. S. Department of Commerce, Bureau of Mines, Bulletin 323.

(22) To understand thoroughly the principles that underlie use of the gas lift as a means of increasing the ultimate recovery of oil from a subsurface structure one must have a knowledge of the characteristics of the sand body and of the conditions in the porous formation within an oil reservoir.

Reservoirs yielding oil and gas may occur in any porous strata. Reservoir rocks are usually sands and sandstones, porous limestones, and fractured shales. In California the reservoirs in which oil and gas have accumulated consist generally of unconsolidated sands resembling beach sands and sandy shales. The capacity of a sand for storing oil varies with the porosity of the sand, which ranges in California from 10 to 40 per cent and averages about 25 per cent. One cubic foot of sand may therefore contain 0.1 to 0.4 cubic foot of oil or, on the basis of average porosity, approximately 1.87 gallons of oil per cubic foot of oil sand.

The irregular size and shape of the pore openings in an oil sand affect materially its frictional resistance to the movement of oil and gas through it; a relatively slight difference in the texture of the sand makes a great difference in the resistance.

Crude oils (petroleums) are present in underground reservoirs as mixtures of hydrocarbons with varying chemical and physical properties. Before the drill has tapped the oil reservoir and before it has been disturbed by natural causes, gas, also of varying chemical and physical properties, is associated with the oil, either in solution in the oil or as free gas above the oil in the structurally higher parts of the natural reservoir. Data collected from various laboratory tests show that the average California crude oil of about 25° A. P. I. gravity will hold in solution slightly less than 0.2 cubic foot of natural gas per barrel of oil per pound of pressure. For practical purposes the volume of gas soluble in a unit volume of crude oil is a straight-line relation for all pressures in the range ordinarily encountered in the oil fields. Dow and Calkin [15] show that the amount of natural gas that crude oil will hold in solution depends upon pressure and temperature and upon the nature of the gas and the nature of the crude. In a particular reservoir the amount of gas held in solution by the oil depends upon the pressure and temperature in the reservoir.

Formation pressures of 1,200 pounds per square inch and greater are often found in the California oil fields where oil is obtained from depths of 4,000 feet and more. According to Dow and Calkin the volume of gas at a pressure of 1,200 pounds per square inch that may be dissolved in a barrel of average oil at 70° F. will be nearly 230 cubic feet. McCollum [16] reports a laboratory test of

[15] Dow, D. B., and Calkin, L. P., Solubility and Effects of Natural Gas and Air in Crude Oils. Repts. of Investigations, Serial 2732, Bureau of Mines, 1926, 13 pp.

[16] McCollum, C. R., California—With Especial Reference to Practical Conservation: Om. Petrol. Inst. Bull. 6, vol. 8, 1927, p. 325.

a particular California oil in which 344 cubic feet of gas was found to be soluble in 1 barrel of oil at a pressure of 1,800 pounds per square inch.

High A. P. I. gravity crudes can usually hold greater volumes of gas in solution than crudes of a lower gravity, (23) and gases with a large percentage of methane are not as soluble as those with a large percentage of ethane and the heavier hydrocarbons. Dow and Calkin found that about 13 per cent more gas dissolved in a 36° A. P. I. gravity crude than in a 25° crude at 350 pounds pressure and 70° F. and that 20 per cent more of a gas containing 39 per cent of ethane dissolved in a certain crude than of a gas containing 5.46 per cent of ethane.

There is a definite amount of gas in an undisturbed natural petroleum reservoir. As previously mentioned this gas may be in solution in the oil, it may be free gas in contact with the oil in the structurally higher parts of the reservoir, or it may occur in both phases. Before a well penetrates the oil reservoir conditions within the reservoir are in equilibrium, pressures are the same throughout; each unit volume of oil presumably has an equal volume of gas in solution, and the formation pressure and volume of gas in solution are maximum.

Nearly all wells in California, especially deep wells, are drilled with mud fluid in the hole so there will be enough back pressure to overbalance the formation pressure against the exposed face of the oil sand in the well when the bit penetrates the reservoir. The flow of petroleum and gas into the well does not usually begin until the hydrostatic head built up by the column of mud fluid in the hole is reduced sufficiently by bailing and swabbing to create a differential pressure between the oil formation

and the well. This differential pressure gradually becomes greater as the mud fluid in the well is replaced by oil and gas. The free gas in contact with the oil expands with the release of pressure within the reservoir; some of the gas in solution in the oil is liberated when the pressure is reduced and also expands with a further decline in pressure. Oil is forced into the well by continuous expansion of the gas bubbles, which are trapped in the pores of the reservoir sands, and to a smaller degree by the expansion of any free gas present above the oil. The action of gravity in moving oil to a well is so slow as to have little practical effect on the expulsion of oil from a sand.

If the gas bubbles are allowed to expand rapidly, as they do when the differential pressure between the formation and the well is large, much of the energy released by the expanding gas will be used up in overcoming the frictional resistance that opposes the expulsion of the oil from the sand. Gas is more mobile than oil, and its movement through the minute, irregular passageways between the sand grains meets with less frictional resistance. It moves toward the well, therefore, faster than oil. This movement results in a loss of energy by slippage of the gas through the oil. Rapidly expanding gas opens channels through the looser parts of the sand, through which the gas escapes to the well without expending much energy in moving oil. The expansion of the gas may be so rapid and its velocity of flow through the looser parts of the sand so great as to exclude the oil from these channels and prevent it from being carried to the well.

Maintaining high back pressure against the producing formation reduces the differential pressure between it and the well. The gas bubbles that enter the well will be small

compared with what they would be if allowed to expand at a lower pressure. Small bubbles meet little frictional resistance when traveling through the pore spaces in the sand, and little energy is consumed in distorting them as they pass through openings of irregular shapes and various sizes. Decreasing the expansion range of the gas (24) bubbles in the sand reduces the velocity of their flow toward the well, thus reducing the probability of formation of channels through which the gas may escape to the well without carrying with it or driving ahead of it a certain amount of oil. More oil per unit volume of gas is moved toward the well because decreasing the velocity of gas reduces its slippage through the oil. Maintaining high back pressure also causes the gas to remain in solution longer. The more gas an oil retains in solution the more fluid the oil, since viscosity is directly proportional to the amount of gas in solution in oil. Surface tension also decreases as the amount of gas in solution increases. Viscosity and surface tension have an important bearing on the rate of flow of oil through a porous formation and upon the energy necessary to cause flow. Limiting the size of the gas bubbles by applying back pressure against the oil sand increases the percentage of pore space about the well available for the movement of oil. This fact and the fact that gas is less likely to channel through the sands when the gas-expansion ratio is decreased permits oil to be produced with a minimum amount of gas.

The gas lift is a means by which an operator can control the back pressure on a producing formation and lessen the proportion of gas produced with each barrel of oil, thus increasing the total ultimate recovery of oil from a porous reservoir.

Back-Pressure Application in Gas-Lift Wells Tubed Below Top of Producing Formation.

(83) When a well is tubed below the top of the producing sand, the pressure against the face of the exposed sand in the well is equal to the gas pressure opposite the producing sand. A cone-shaped area of drained sand, with the apex of the cone at the lower end of the eduction tube, will theoretically exist about the well. (See fig. 33.) The base of this cone (top of oil sand) will increase in area as production continues if the bottom of the eduction tube is not raised. The gas pressure in the area of drained oil sand will equal the gas pressure in the well, and the differential pressure between the saturated oil sand and the drained sand will cause the oil to flow to the well. Decreasing the back pressure in the well will allow some of the gas that is in solution and occluded in the oil in the saturated zone to expand, driving some oil ahead as it expands and carrying a certain amount with it, due to its velocity, into the area of least resistance (the drained area). Losses due to friction in the drained area will be less than in the saturated zones and the gas will flow with increased velocity, slipping through and by-passing much of the oil that it had formerly driven into the drained area. As soon as the gas enters the drained area, the delivery of oil through the partly depleted sands to the well depends upon the carrying capacity of the gas due to its velocity.

Although the pore spaces in the drained area are filled with gas, a large percentage of the original oil contained in the sand remains attached to the sand grains. The amount of oil remaining in a depleted oil sand has been estimated by various authorities to range from 60 to 80 or more per cent of the original oil in the sand. This oil is retained by the force of adhesion on the sand grains and by

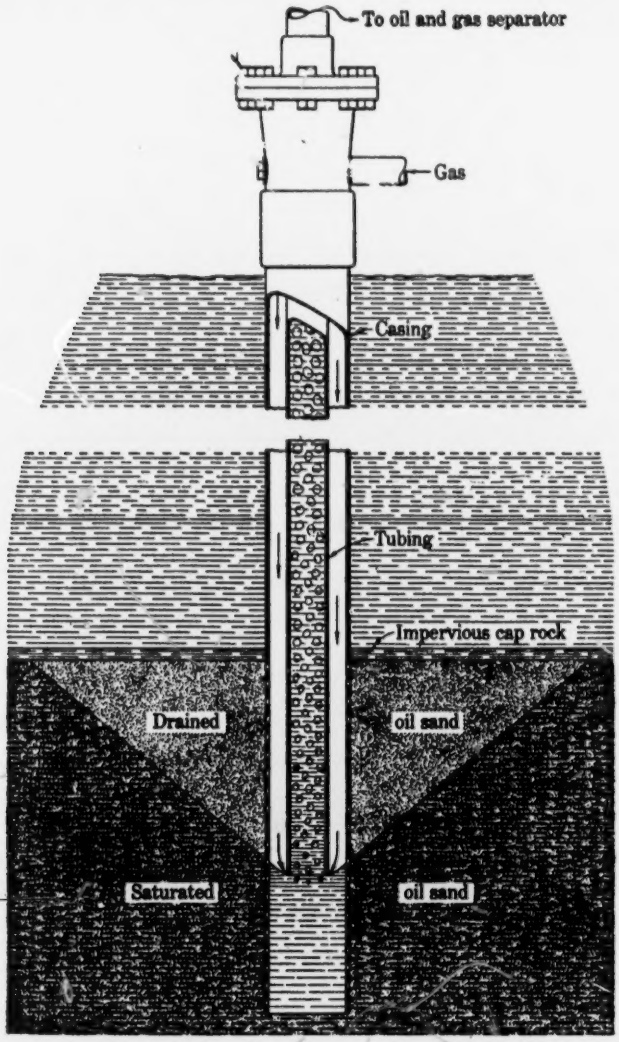

FIGURE 33.—Sketch illustrating drainage cone existing theoretically in oil sand about gas-lift well when tubed below top of sand

capillary attraction between the sand grains. A certain amount of gas is held in solution by the oil surrounding the sand grains and is released only upon the reduction of pressure. Increasing the back pressure in the well will cause some of the free gas within the sand pores to be dissolved by the adherent oil, thereby decreasing the viscosity and surface tension of the oil and rendering it more susceptible to being detached from the sand grains and carried along

(85) by the expanding gas. Increasing the back pressure, however, retards the velocity of the gas so that its capacity to carry oil is reduced. Decreasing the back pressure allows gas to come out of solution from the oil which is attached to the sand grains, causing the oil to adhere still more tenaciously to the sand grains because of its higher viscosity and surface tension. Under reduced back pressures the velocity of flow of gas through the drained sand is increased and may be such—depending upon the differential pressure—that it channels through the areas of least resistance and escapes to the well without carrying with it a proportionate amount of oil. The efficiency of expulsion of oil from a sand penetrated by a well that is tubed below the top of the producing formation depends, therefore, mainly upon the proper balance between the velocity of flow of gas through the drained area and the forces resisting the movement of oil and gas through the openings in the partly depleted sand. Experience has shown that in wells so tubed, relatively high back pressures result in low formation gas-oil ratios, indicating more efficient recovery of the oil from the sand.

The energy required for maximum efficiency of expulsion bringing about increased ultimate yield also depends partly upon the resistance to flow offered by the oil sand. Oil sands vary in texture; the size and shape of the pore spaces are not the same in all sands or in all parts of the same sand. Fine-grained sands have smaller pore spaces and offer greater resistance to the flow of oil and gas than sands composed of large, well-roundeu, smooth grains. Oils differ also in gravity, viscosity, and surface tension, and all gases do not have the same physical characteristics. Pressure conditions are not the

same in all wells or in one well, neither is the rate of gas flow constant in producing wells. Flow conditions also vary in the same sand, owing to greater formation pressures as the distance from the well increases. Farthest from the well the oil will be expelled principally by the expansion of the gas bubbles, and the expulsion of oil will be inefficient because under the existing pressure differential between adjacent sand grains the bubbles will travel toward the well incompletely expanded. The bubbles will continue to expand as they approach the well until they become so large under the lower back pressure prevailing about the well that energy will be lost in creating velocity and in distorting the bubbles as they flow toward the well.

One may see from the above discussion that the application of back pressure in gas-lift wells up to a certain point that is based upon the proper balance of forces assisting and opposing the efficiency of expulsion results in the production of oil with a low formation gas-oil ratio. A reduction or increase in back pressure below or above that giving the maximum efficiency of expulsion results in an increase in the volume of gas produced with each unit volume of oil recovered, and the operator should make every effort to flow his wells under the back pressure that will result in the production of the most oil ultimately.

The efficient utilization of the gas energy latent in the formation gas is made more difficult in many California fields in which the producing formations are composed of two or more oil zones separated from one another by impervious shale partings. A producing formation with the well tubed as represented in Figure 34 will necessitate an analysis embodying the principles just expounded. The oil produced

from zone *A*, Figure 34, will be that of a well tubed below the top of the oil sand; the recovery of oil from zone *C* will be similar to that of a well tubed above the top of the oil sand; whereas in zone *B*, both conditions will prevail. The formation pressures in the different zones usually differ so that a back pressure in the well, based on the most efficient expulsion of oil from one zone, may result in highly

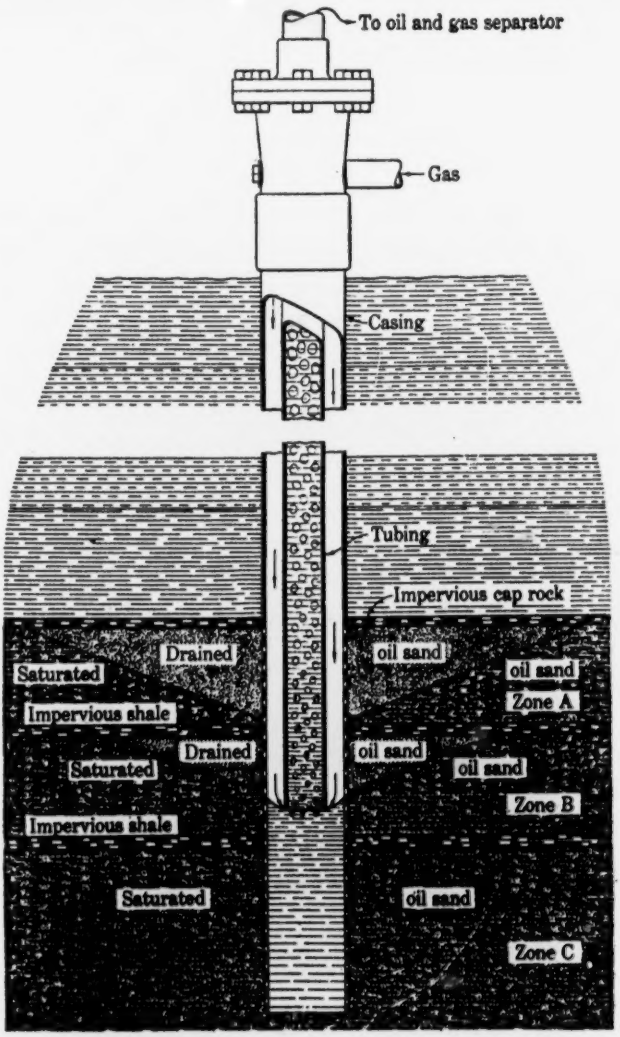

FIGURE 34.—Sketch illustrating drainage conditions in producing formation composed of three oil zones separated by impervious shale when gas-lift well is tubed into middle zone

inefficient oil recovery from the other zones. For this reason many operators tube their gas-lift wells nearly to the bottom, thus placing a high back pressure on all of the producing zones. Tubing wells low and holding a high back pressure on the producing zones may result in a temporary reduction in oil production, but if the formation gas-oil ratios are minimum the ultimate recovery of oil from the producing zones will be much greater than if less back pressure had been

(87) held against the producing formation. Other operators tube their wells opposite the producing sand previously determined as the most prolific source of oil in the well. This determination is usually made either from core samples taken when the well was drilled or from tests with tubing and a double packer of the productive capacity of different zones in the well. The packer method consists of running a string of tubing on which two packers are spaced a short distance apart. The tubing is perforated between the packers. The tubing is lowered by successive stages until the location of the most prolific oil-producing zone is found. The packers are then withdrawn and the tubing is rerun into the well and bottomed, usually at the top of the most productive zone.

No matter where the tubing is bottomed in a well that has penetrated a thick sand with numerous shale partings, experimental work in controlling the formation gas will reveal a certain back pressure under which the minimum volume of formatior gas will accompany a barrel of oil into the well.

Conclusions.

(115) The gas lift has become a recognized method of flowing oil wells. Its most valuable function is to bridge the gap of inefficient production that usually exists after natural flow in wells is no longer efficient and before production is small enough to be handled by plunger pumps. Experimentation to increase the efficiency of the gas lift when small quantities of oil are lifted has developed methods of flowing small producers by gas in direct cost competition with plunger pumps. Developments in the future may

even make it profitable to lift oil by gas in small producing wells that ordinarily are pumped by central jack plants.

Although the gas lift possesses many advantages over other lifting methods it is not a cure-all for all pumping difficulties. The gas lift will not operate successfully in all wells; even in favorable wells the use of the gas lift will not produce the desired results if it is improperly installed and operated.

Fundamental data concerning the operation of the gas lift are meager. Little is known about the velocities and resistance to flow of oil and gas mixtures in vertical pipes, the design of tubes best adapted to the upward flow of gas and oil where the gas is expanding constantly, and the rate of expansion of the gas in the eductor tube. A knowledge of these and many other data of a fundamental character is necessary to design, install, and operate gas-lift systems efficiently. Until such data are vailable experience and the ability to correctly interpret well records and underground conditions will be necessary in making gas-lift installations.

Conditions in oil wells are changing constantly, and because efficient and economical operation of the gas lift depends mainly upon the engineers' and operators' ability to meet changing conditions of pressure, rate of flow of oil and gas into the wells, and fluid levels, continual experimentation on wells is necessary. It is imperative, therefore, that accurate detailed records be kept of the

performance of the well and of changes in operating methods. Accurate measurements of the volume of gas pumped into wells and taken from wells with the oil make it possible to compute the volume of gas flowing into the well with a unit volume of oil. The formation gas-oil ratio has become a yardstick by which the efficiency of a well is measured; high ratios usually indicate that the expulsion of oil from the reservoir sands is inefficient. Every effort should be made to maintain formation gas-oil ratios low and gas-oil ratio trends at a level or minimum upward gradient if greater ultimate recovery of oil from reservoir sands is desired.

Although the technique of the gas lift is still undeveloped and fundamental data are lacking, production engineers have secured results that justify continued use of the gas lift wherever conditions are suitable. Although it is an axiom that each well is a separate problem which requires individual study and experimentation for maximum lifting efficiency, certain general hypotheses are agreed to be applicable to nearly all wells. The author has therefore attempted to point out operating facts and generalized practices in the hope that some of the time and money now wasted through duplication of experimental work, lost production, and inefficient lifting methods and practices will be saved by their use.

Origin of the Rich Pressure of Natural Gas in the Trenton Limestone of Ohio and Indiana.

By Edward Orton.

Annual Report Smithsonian Institution to the Congress, July 1, 1921, at page 155. Read before Geological Society of America, December 26, 1889.

For my own part, I have felt certain for more than two years that the rock pressure of gas in the Trenton limestone of Ohio and Indiana is hydrostatic in origin, and I have published a number of facts that seem to me to give support to this view. I find that some sagacious operators in the new gas and oil fields are coming to the same ground. They have become thoroughly satisfied by their own experiences that the root of rock pressure is to be found in the water column that stands connected with the porous rock in which the gas and oil are contained. In the present paper I desire to present to the Geological Society a few facts and conclusions bearing upon the subject.

The Data for the Hydrostatic Theory.

The first question is, What are the facts as to the rock pressures of the gas rock in question and what relations do they bear to the depths of wells and other conditions in the Trenton limestone? The answer is not as full and definite as may be expected, certainly not as may be desired. There is but one datum in the development of a gas field in which the normal gas pressure can be ascertained, and that is when the first well reaches the reservoir and releases the long-imprisoned and greatly compressed gas. But often this favorable opportunity is lost, and gauges are not applied to wells until the energy of the first flow is somewhat abated. Again, different

wells in the same field, as Findlay, for example, give different results. The wells vary with the depth at which the gas rock is found. This factor is found to be an essential one, as will presently be shown, in connection with rock pressure. Moreover, gauges are sometimes inaccurate and their errors come in to confuse the study of the subject. Furthermore, the exact depth of the wells and the exact altitude of the surface where they are located cannot be ascertained in all cases. Small errors of this sort must be provided for, and there also enters into the discussion a question as to the specific gravity of the water which is to be made the moving force of gas and oil. The water found in association with these substances is never fresh. It is always saline and often highly mineralized. The weight of fresh water to the square inch is 0.43285 pound for 1 foot in height (I use Professor Lesley's tables). The average weight of sea water is 0.445 pound to the square inch for 1 foot; but the mineral waters with which we find the Trenton limestone saturated often reach a much higher figure. An examination of several specimens shows that a column 1 foot high would weigh to the square inch 0.476 pound. In fact, some of these waters are more like bitterns, and their columns would equal or exceed 0.5 pound per foot. Bearing these several sources of ambiguity or uncertainty in mind, we can consider the records of pressure, depth, and the other factors that are accessible. The figures as to pressure have already been summarized in a preceding paragraph, but they will be repeated in an accompanying tabular statement. Before coming to this, however, let me in the briefest terms review the conditions under which gas, oil, and salt water exist in the Trenton limestone. The uppermost beds of the great Trenton for-

mation in northwestern Ohio, central and northern Indiana, Michigan, Illinois and Wisconsin, consist of a porous dolomite 5, 50, 100, or even 150 feet in thickness. Sometimes the dolomite is found in a continuous body, but oftener in interrupted beds. This part of the formation has outcrops in the Manitoulin Islands of Lake Superior and in the Galena limestone of Illinois and Wisconsin. In the gas and oil fields, it is found lying in terraces and monoclines, or flat arches, 800 to 1,500 feet below the surface; and these several features effect the separation of the varied contents of the porous rock. The boundaries of gas, oil, and salt water are easily determinable and are scrupulously maintained in the rock, except that as soon as development begins the salt water is always the aggressive and advancing element. When the drill descends into the gas rock proper dry gas escapes; when into the contiguous and lower-lying terrace, oil accompanied with gas appears, as already described; but at a little lower level salt water is struck, and this rises promptly in the well, sometimes to the point of overflow. Far out from the narrow ridges or restricted terraces where gas and oil are found the salt water reigns undisturbed, and wherever reached by the drill it rises in the wells as in those already described. It would be in the highest degree absurd to count the little pockets of gas that are found in the arches the cause of the ascent of this ocean of salt water a score or a hundred miles away. The rise of the salt water is unmistakably artesian. It depends on hydrostatic pressure, as does the flow of all artesian wells, and its head must be sought, as in other like flows, in the higher portions of the stratum that are contiguous.

The nearest outcrops of this porous Trenton have been already named. They are found in the shores of Lake Superior at an altitude of about 600 feet above tide. It is certainly significant that when an abundant flow of salt water is struck in a boring in northern Ohio or in Indiana,

no matter at what depth it rises generally, about to the level of Lake Superior; or, in other words, about 600 feet above tide. If the mouth of the well is below this level, as is the case in the Wabash Valley, the salt water overflows. On the shore of Lake Erie the water rises to within 20 feet of the surface; in Findlay, to within 200 feet. The height to which the salt water rises in any portion of the field is one of the elements to be used in measuring the force which can be exerted on the gas and oil that are caught in the traps of the terraces and arches of the porous Trenton limestone.

Why, then, is not the rock pressure of the gas the same in all portions of the new horizon? For the obvious reason, I reply, that there is a varying element involved, viz., *the depth of the rock below sea level.* The surface elevations at the wells vary greatly, and the wells of the same depth consequently find the gas rock in very different relations to sea level.

The Test of the Hydrostatic Theory.

It is obvious that if an explanation of the rock pressure of the Trenton limestone gas is attempted on this basis, there are facts enough now at command to substantiate or overthrow it. By the facts it must stand or fall. In the accompanying table I have indicated the following lines of facts as to strictly representative wells in the leading districts of the new gas fields, viz., (1) location, (2) depth at which gas is found, (3) relation of this depth to sea level, (4) the initial rock pressure of the gas. In regard to the last line of facts I have taken, in almost all cases, figures that I have myself verified. (5) A fifth column I add, in which the pressure due in the particular well is calculated from the two following elements, viz., an assumed elevation of the salt water to the Lake Superior level, or 600 feet above tide; and, secondly, an assumed specific gravity of the salt water of the Trenton of 1.1, which gives a weight of 0.476 pound to the foot.

Locations.	Depth to gas.	Relation of gas rock to sea level (below tide).	Original or first observed pressure.	Calculated pressure 1 foot= 0.476 pound.
Ohio	Feet	Feet	Pounds	Pounds
Tiffin, Loomis & Nyman well	1,500	747	650?	641
Upper Sandusky, well No. 1	1,280	478	515	513
Bloom Township, Wood County, Godsend well	1,145	395	465	473.6
Findlay, Pioneer well	1,120	336	450	445.7
St. Mary's, Axe well	1,159	238	390	398.8
St. Henry's, Dwyer well, No. 1	1,156	200	375	385
Indiana				
Kokomo, well No. 4	936	98	320	332
Marion, well No. 3	870	78	323	322.7
Muncie	900	(*)	300?	286.6

* At tide level.

These figures seem to me to settle the question as to the origin of the rock pressure of the gas in this formation. I feel sure that nicer determinations of the facts involved as to altitude and depth would bring a still closer agreement between columns four and five. I will ask you to note in particular the facts as to the St. Mary's and the St. Henry's wells. They have practically the same depth, 1,159 and 1,156 feet; but there is a difference of 38 feet in the depth of the gas rock with reference to sea level. There is a corresponding difference in the rock pressure of 15 pounds, as recorded. The difference in rock pressure due to this 38 feet by calculation is 13.8 pounds, or practically, 15 pounds. I presume that column five is as near the truth in this particular as column four. The gauge would quite certainly be reported 385 pounds if it lacked but 1 or 2 pounds of that number.

The Laws of Gas Production.

The laws of gas and oil production and accumulation are coming to light more clearly in the flat country of Ohio and Indiana than they have ever done among the hills and valleys of the older Alleghany fields. As it seems to me, no more important deduction from the new districts has been reached than the law now stated, viz.: *The rock pressure of Trenton limestone gas is due to a salt-water column, measured from about 600 feet above tide to the level of the stratum which yields the gas.* The column can be conveniently counted as made up of two

parts, viz., a fixed length of 600 feet added to the depth of the gas rock below tide.

If this explanation is accepted as satisfactory for Trenton limestone gas, I venture to suggest that the fact will go a great ways towards rendering probable a like explanation for rock pressure in all other gas fields; but I will not at the present time venture to extend it beyond the limits I have named. I am aware of certain facts, or at least supposed facts, from the older fields that seem difficult of explanation on this basis.

There are a few obvious inferences from this law to which I venture to call your attention in closing this paper:

(1) There is no danger that the great gas reservoirs of today will "cave in" or "blow up" after the gas is withdrawn from them. The gas will not leave the porous rock until the salt water obliges it to leave by driving it out and taking its place.

(2) This doctrine lays the ax at the root of all the optimistic theories which blossom out in every district where natural gas is discovered, and especially among the real-estate operators of each new field, to the effect that nature will not fail to perpetually maintain or perpetually renew the supplies which we find so delightfully adapted to our comfort and service. So far as we are concerned it is certain that nature has done about all that she is going to do in this line. In her laboratory a thousand years are as a single day.

(3) No doctrine could exert a more healthful influence on the communities that are enjoying the inestimable advantages of the new fuel than this. If it were at once accepted it would add years to the duration of these precious supplies of power. The ignorant and reckless waste that is going on in the new gas fields is lamentable. The worst of it comes from city and village corporations that are bringing the gas within their boundaries to give away to manufacturers whom they can induce on these terms to locate among them. To characterize the use of a million feet of natural gas a day, in a single town, for burning common brick, for example, or in calcining common limestone, there is a good word at hand, viz., *vandalism*.

(4) If this doctrine of the rock pressue of gas is the true one, the geologists who have to deal with the subject and the communities that have found a supply owe it to themselves to keep it prominently before the people who are especially interested. They may make themselves temporarily disagreeable thereby, but by just so far they convince those that are interested, they lengthen the life of these precious supplies.

Summary by Ernest K. Parks of "Analytical Principles of the Production of Oil and Gas and Water From Wells" by Stanley C. Herold, 1928.

(Herein Mr. Parks presents a summary of the theory set forth in the foregoing treatise, emphasizing its relation to the problems of oil and gas field development, operation and rejuvenation. His thorough study of the theory itself and his knowledge of oil and gas field practice undoubtedly place him in a position to select and explain in not too technical language those items of greatest concern to the executive or operator. It is assumed that this executive or operator desires information concerning the nature of the subject treated, the author's method of attack, and the value of the work to the industry, without entering upon a detailed study of the contents of the book.—S. C. H.)

A well, properly fitted with its casing, its tubing, its head equipment, and any other accessory apparatus, such as a pump or a gas lift, is, after all, merely the orifice of a natural reservoir that is capable of producing oil and gas. It is the hole through which these fluids are brought to the surface. To serve efficiently it must of course be suitably equipped and properly maintained in condition during operation. By means of this hole we obtain not only production itself, but, since it is our only point of access to the productive formation lying below, we obtain also the data of such production. From these data we know the behavior of the reservoir; consequently we know how best to treat the reservoir and what to expect of it in return. It is the reservoir which is of greater concern to us. Without it the well would have no value.

The industry asks, "What do we know about the physical laws governing the habits of oil and gas deposits, and the laws which govern and influence the extraction of oil and gas from those deposits?"[2] We may assume that the answer is indeed given in the foregoing treatise.

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[2] This question was framed by M. E. Lombardi, Standard Oil Company of California, and presented to the Pacific Coast Technical Sub-Committee of the American Petroleum Institute's Gas Conservation Committee, San Francisco, September, 1927.

Seven so-called primary functions of performance—pressure, velocity, volume, acceleration, energy, power, and time—give us the key to the entire situation within the reservoir. We must know about *pressure,* because this determines whether or not the reservoir will produce; it determines the rate of production; and it is necessary to the calculation of future production. *Velocity* is merely a convenient term for the rate of production. *Volume* is the total amount of fluid to be produced. *Acceleration,* or the change in the rate of production is an essential feature of our studies in decline curves. *Energy* is utilized in the work of production, and it is related to the amount of gas accompanying oil within the reservoir. *Power* is the rate at which energy leaves the reservoir, and it is also the rate at which gas is produced with oil. Obviously it is a feature of direct application in the problem of gas-oil ratios. *Time,* of course, is vital to all our calculations.

In contrast to these primary functions which deal with the behavior of the reservoir, as observed at the well, there are the secondary functions. These deal with the events and conditions which take place or exist within the reservoir itself. They pertain to such matters as the source of energy within the reservoir, the conservation of this energy, the drainage radius and the drainage area of wells producing from the reservoir, the encroachment of water upon the pool of oil and upon the well itself, the fitness of the reservoir formation for the storage of gas and for reserves of oil, the percentage recovery from the formation by natural flow, the fitness of the reservoir formation for the restoration of gas pressure, and for the forced drive with water, air, or gas. These features are

called secondary because they are to be identified by means of the primary functions, and not because they are of less importance.

It is evident, then, that we have sufficient reasons for understanding the nature of the primary functions, their characteristics, their interrelations, and their variations during production. By means of them we learn to regulate the performance of the well to the best advantage, in that we know the proper back pressure to be applied, the most desirable rate of production, the most economical gas-oil ratio to be attained, and the most desirable rate for pumping or lifting the oil from the bottom of the well. Upon them we base our forecasting of the future performance of the well. For this they prescribe the necessary data to be collected in the field, and they indicate the manner in which these data should be used. The collection of irrelevant data is to be avoided, and the loss of relevant data by neglecting the proper observations is to be prevented. Finally, as we have just noted, they indicate to us the events and conditions within the reservoir. By means of them we learn the proper location and spacing of wells in developing the field, we know the necessity or lack of necessity in purchasing protective acreage, and we know the amount and security of our reserves.

The primary functions are related differently under various circumstances, and, as we might expect, the secondary functions are different in correspondence with them. These differences are not to be confused with minor features that are due simply to local circumstances within the vicinity of the single well or group of wells

in the field. It is true that such local variations in structure and texture, as are known to exist in our fields, combined with a greater or less proximity of water, tend to make each well distinguishable from every other well in the same field, and each field distinguishable from every other field in existence. In spite of these features all natural reservoirs possess properties which permit us to classify them into three distinct groups. These groups, called "controls," are clearly defined, and they are therefore easily recognized in the field. Each control has its distinct set of performance curves in accordance with different relations between the primary functions. Every natural reservoir must belong to one of the three.

The three controls are as follows:

1. *Hydraulic Control.*—Pressure and rate of production remain constant during the course of production from the reservoir. The situation is analogous to that of a water tank delivering its water with a head, or depth of water, maintained at a constant level within it by the necessary inflow of more water.

2. *Volumetric Control.*—Pressure and rate of production decline and approach zero during the course of production from the reservoir. The situation is now analogous to a water tank delivering its water with a head declining in accordance with production from it.

3. *Capillary Control.*—Pressure and rate of production also decline and approach zero during the course of production. The decline here takes place in accordance with the characteristics of the "Jamin capillary tube," a tube of capillary bore, filled with alternating globules of liquid and bubbles of gas.

Natural reservoirs in Hydraulic and Volumetric controls perform according to the well-known laws of hydraulics. As we see, the only difference between them lies in the fact that the pressure head remains constant in the first one, while it declines in the second one. The fact that the reservoir is associated with a porous formation does not affect the laws of production, as these are displayed by the pressure and rate of production curves. Only the numerical values are different in the presence of this formation. The column of liquid bearing its weight upon the bottom of the well is the source of the energy; consequently the water surrounding the pool of oil must be conserved. The encroachment of this water upon the pool and upon any well in the pool is inevitable in time. The drainage radius and drainage area of each well in the pool is coextensive with the formation itself. This means that all wells are producing from the same space. These reservoirs are unsuitable for the storage of gas and for oil reservoirs, if wells under other ownership are producing from the same formation. On the assumption that there is at least one well to each minor [illegible] in the structure, recovery is one hundred per cent of the mobile oil in Hydraulic Control and the same in Volumetric Control, depending upon whether or not the pool is depleted before the pressure and rate of production curves reach zero in the course of production. It is useless to attempt the restoration of gas pressure within these reservoirs, for the gas is not the source of the energy. The forced drive with water, air, or gas is unnecessary on our part, for Nature is already driving with water—with that water which

surrounds the pool and extends up the general dip of the formation.

The Kern River Field of California is a good example of production in Hydraulic Control, and the Coalinga Field of the same state is a good example of production in Volumetric Control.

The discovery of Capillary Control in our producing fields and the complete analysis of its important economic features constitute the outstanding contribution of Mr. Herold's work. While "Jamin action," as illustrated by the behavior of the Jamin capillary tube, plays a role in all natural reservoirs in porous formations when both liquid and gas are present, its role is a subordinate one in Hydraulic and Volumetric controls, but a predominant one in Capillary Control. The situation as explained by Capillary Control, with respect to both primary and secondary functions, accounts for the supposed erratic behavior of many of our oil and gas wells.

Jamin action is due to alternating globules of liquid and bubbles of gas within channels sufficiently small to permit capillary forces to be an important feature. The globules, on the release of pressure at one end of the channel, become distorted in shape, and in this condition they offer a resistance to the pressure tending to drive both the liquid and the gas toward this end. Consequently the amount of liquid and gas to issue from the channel depends upon the intensity of the pressure bearing upon the fluids within it.

The action of these globules and bubbles is easily observed in the Jamin tube having glass walls. A porous formation may be taken as a bundle of such tubes radiat-

ing in all directions from any well which penetrates it. The hydrostatic pressure bearing upon a pool of oil in the vicinity of the well may be sufficiently intense to overpower the resistance of the globules. In this case the well produces either in Hydraulic or in Volumetric Control, depending upon whether or not this hydrostatic pressure is constant during production. But if this hydrostatic pressure is absent, or if it is not sufficiently intense to overpower the resistance, the well produces in Capillary Control.

The source of energy in reservoirs of Capillary Control is due to gas pressure; consequently the conservation of this energy is only to be attained by the conservation of the gas within the reservoir. The drainage radius of a well in such a reservoir is of limited length, depending upon the intensity of the pressure tending to move the oil toward the well, and the intensity of the resistance offered by the globules in the path of movement. The drainage area of a well is circular—perhaps an imperfectly circular one because the texture of the formation is not the same in all directions from the well; nevertheless the area is a closed one, and it does not cover the extent of the formation. Water surrounding the pool of oil cannot encroach upon it. If the well happens to be located near the edge, water of course can encroach upon the well, for this water lies within the drainage area of the well. The formations having such characteristics are eminently suited to the storage of gas and to reserves of oil. Neighboring wells drain from a property only within a limited radius, and an offset well prevents even this. The percentage recovery from the formation by natural flow varies considerably in different

fields of this control, for the recovery depends entirely upon the radius of drainage of the wells, and the spacing between them. In any given field we can actually determine the recovery. The restoration of gas pressure is entirely proper, for the gas, as just stated, is the source of all energy within the reservoir. Complete recovery is only to be attained by the forced drive with water, air, or gas. We must apply a pressure at one well of sufficient intensity to overpower the resistance offered by the globules between it and another well. Nature is not flooding with water in these reservoirs, since the hydrostatic pressure is either absent or not of sufficient intensity; consequently we must flood the formation ourselves, if we want the oil which remains after natural flow and pumping have reduced production to the low rate that is said to be the economic limit of operation. Nature permits us to imitate her in flooding, but in this she confines us to a local area within the vicinity of the input and output wells. The area proves to be elliptical in shape, and its dimensions can be determined in any case.

There are, as we have seen, two controls—Volumetric and Capillary controls—in which pressure and rate of production decline in the course of production. The secondary functions—the events and conditions within the reservoirs—are very different in the two. We cannot make personal visits to the formations. How shall we decide which of the two controls we have in any field of interest to us? Easily and efficaciously by means of the primary functions. As stated above, they indicate to us the events and conditions within the reservoir.

The pressure curves are the same in both declining controls; consequently we cannot tell from pressure curves alone the control of the field. The rate of production curves, however, are different. To be absolutely certain of the control we should have both pressure and rate of production curves. We have used both in gas field practice for several years, and there seems to be no reason why we should not use both in oil field practice. Where we have them we can plot the values of pressure and rate of production in percentages of the initial values against time. If the rate curve lies above the pressure curve we have Volumetric Control, but if it lies below the pressure curve we have Capillary Control. We see how easy this is. As a matter of fact the gas engineers in the fields of Ohio, Pennsylvania, New York, and the Canadian provinces adjoining, have long ago recognized the fact that the rate of production curve underlies the pressure curve. (They have been producing from reservoirs in Capillary Control without being aware of the significance of it.) They found that the well-known laws of hydraulics are not applicable to their gas wells. They were right.

Another way by which the distinction between the two controls can be made is by plotting the rate of production against the pressure on logarithmic paper. If the points do not lie on a straight line they can be made to do so approximately by shifting them to the right or to the left in the usual manner. If this line has a slope of one to two we have Volumetric Control, but if it has a slope of three to two we have Capillary Control. We also see how easy this is. As a matter of fact gas engineers in Kansas and Oklahoma have long ago rec-

ognized the three-to-two slope. (They likewise have been producing from reservoirs in Capillary Control without being aware of the significance of it.)

Oil wells in the regions mentioned above also produce from reservoirs in Capillary Control. Until recently the oil engineers have not had pressure data on their wells; so the situations with respect to the two curves are not very well known among them. Nevertheless they have frequently noted that the rate of production curves have a slope of three to one on logarithmic paper. This is the slope for Capillary Control. If the reservoirs were in Volumetric Control these curves would have a slope of one to one. All these circumstances are in agreement with the fact that there are two declining contr ols.

The Cushing Field in Oklahoma is an excellent example of production in Capillary Control. It has been particularly noted there that edge water does not encroach upon the pool, as it does in the Coalinga Field.

If we say that in the Kern River and Coalinga fields every barrel of oil produced at one well means one barrel less for some other well or group of wells, and that such is not the case in the Cushing Field, we are basing our statement upon a knowledge of the secondary functions of producing reservoirs in the three controls. But how can we have this knowledge? The answer is: by mathematical analysis. This simply means that from the known properties of fluids, such as viscosity, surface tension and capillarity, and from the known laws of physics, such as Boyle's Law, Henry's Law, and the laws of fluid mechanics, we can proceed with mathematical operations that are mostly algebraic and geometrical in their nature,

and derive results which can be interpreted in terms of the producing reservoir. Of course we know in advance what we wish to determine; consequently we continually steer our mathematical course in that one direction until we arrive at our destination. Upon arrival we cannot be sure of ourselves until we verify the situation. Now this verification is a simple matter in the case of oil and gas production, for we have been noting the performance of wells for many years. The experience we have already had with producing properties is generally sufficient for us to decide whether or not our results are correct. We may expect different results in the three controls; therefore we must be careful in judging them from our experience. If our experience should be confined to reservoirs of one control, it is almost certain that we will question results which pertain to a reservoir of a different control. Where question arises, perhaps the best we can do is to ask someone who has had experience in the other control if he can say that the result is correct.

By mathematical analysis Mr. Herold leads us to the analytical principles of production. But what are analytical principles of production? They are simply laws pertaining to production. We have had some of them for many years. Take the *law of equal expectation* as given by Lewis and Beal:[3] "If two wells under similar conditions produce equal amounts during any given year, the amounts they will produce thereafter on the average, will be approximately equal, regardless of their relative ages." This is one analytical principle of production.

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[3] J. O. Lewis and Carl H. Beal, "Some New Methods for Estimating the Future Production of Oil Wells," Transactions of the American Institute of Mining Engineers, Vol. LIX, February, 1918, pp. 492-520.

Take another, the *equal production per pound decline law* of unknown authorship: "For equal amounts of decline in the pressure at a well equal amounts of oil are produced." By mathematical analysis we find that the first of these laws is a correct one, regardless of the control, provided the two wells being compared are not in different controls. Likewise by mathematical analysis we find that the second of these laws is correct for wells which produce from reservoirs in Volumetric Control, but not correct for those which produce from reservoirs in Capillary Control.

These two laws, as stated, illustrate to us a very important matter. Laws, or analytical principles—whichever we wish to call them—can be determined by carefully observing wells during production; they can be determined without mathematical analysis. Then why resort to mathematical analysis at all? Not all of us are fluent in mathematics; some of us cannot see anything about a producing well in an equation. Why not study the well itself, and leave the mathematics to those who like it? But if it were not for mathematics we would not know that these very two laws have restrictions in their application. Furthermore, it is quite likely that there are other laws of easy application which it might profit us to know about. Instead of attempting to find them by months of observation at the wells, why not spend a few minutes with mathematics? If we like them when we get them we can apply them; if not, we can discard them and look for others. Then there are all those questions which the industry asks of us concerning all those events and conditions within the producing reservoir. There are analytical principles which pertain to them.

Years spent in observations at the wells have not given, and cannot give, the information that we feel we must have in order to operate our properties to the greatest advantage. A few hours spent with mathematics will give us that information.

Many new analytical principles of production are brought to light in the present treatise. So long as they are new we must have their proofs; otherwise we can hardly afford to accept them. For this reason the mathematical proofs are included in the text. When we are more familiar with these principles, we can probably get along without proofs. Until then, it will be well at least to have them available. Proofs of necessity appear in the form of equations. Verifications in the field are often only of an incidental character. They cannot always be relied upon, unless we know well the mathematical relation between the verifying observations and the principles themselves.

Mathematical analysis is not dependent upon so-called unknown factors of production. But how can analysis proceed without evaluating the effects of such properties as viscosity, surface tension, and capillarity? It is of first importance to know *how* the factors affect the pressure, the rate of production, the volume to be produced, and so on, rather than to know *how much* they affect these things. The "how" really determines the form of the equation, while the "how much" merely determines the value of some constant which appears in the equation. We can call this constant *"K"*, and be assured that it represents the unknown factors of production. In the statement of any law, such as the two given above, the situation is so worded that undetermined constants do

not appear in the expression. The author is therefore justified in handling K as an unevaluated constant throughout his work. This simplifies the study of production considerably. While the unknown factors are acknowledged as existing, their values remain unevaluated, and the result is the same as if they had been evaluated.

It is now clear how this treatise simplifies the solution of problems encountered in oil and gas field practice by:

1. Resolving the principal features of production—features observed at the well—into seven primary functions, the relations of which to one another are systematically developed.

2. Classifying oil and gas reservoirs into three controls.

3. Establishing the relations between the primary and secondary functions of reservoirs.

4. Describing the secondary functions of reservoirs.

5. Removing from consideration all unknown factors of production.

A further simplification is provided by the adoption of the method of measuring pressure and volume long ago established by the hydraulic engineer. Pressure is expressed as "effective pressure" and volume is expressed as "available volume" under the particular conditions regarding back pressure at the well. From this it follows that the rate of production should be expressed as the "actual rate" under the particular conditions regarding back-pressure at the well, and not as an "open flow rate" so frequently dealt with in gas field practice. By this method the calculations concerning liquids, gases, and vapors are made in the same manner. The fact that these fluids behave differently when subjected to changes in pressure does not influence the method of calculation. Instead of such words as "effective," "available," and

"actual," required to suit the various functions, the one word "potential" is applied to all of them. Thus the potential pressure is the effective pressure, the potential volume is the available volume under the given conditions, and so on. No change is made in naming the units of the functions; pressure appears in pounds per square inch or feet of liquid, volume appears in barrels or cubic feet at atmospheric pressure, and rate of production appears in barrels or cubic feet per day, per week, per month, and so on. Undoubtedly this method of placing calculations on a single basis for all fluids will be appreciated by the oil and gas engineer.

The classification of reservoirs, the consequent classification of problems concerning production from them, and the simplification of the solution of these problems all tend toward more efficient operations in our oil and gas fields.

Throughout the treatise much emphasis is placed upon the graphical representation of well performance. Curves for pressure decline rate of production, cumulative production, and so on, are explained for each control under varying conditions of production. Curves plotted upon logarithmic paper are also explained. Logarithmic paper is a valuable tool in the hands of the oil and gas engineer; it has been in use for some years yet no book has heretofore discussed the properties of this paper with respect to production from wells. A thorough understanding of all graphical methods will assist the engineer in his calculations. Short cuts will suggest themselves, and greater precision on the whole will result from this study.

Mr. Herold's work is comprehensive in the theory of production. He does not deal with hypotheses of production. The principles set forth are already abundantly verified in oil and gas field practice. These principles

are fundamental; they do not depend upon local features within the vicinity of the well or group of wells. They may be compared with the law of gravity in that they hold regardless of local conditions. The application of the principles will reveal the local features. These features need not be known in advance of application. The principles are offered to us in lieu of costly and indecisive experiments in our laboratories and in our fields. Misconceived notions regarding the conservation of gas pressure, the restoration of gas pressure, the percentage recovery from the formations, the application of back pressures, and the drainage of properties by the adjoining wells of others are avoided by understanding these fundamental principles. These things are only misconceived when applied to the wrong control; otherwise they are properly conceived. Thus it becomes clear that we must know the control of our fields from the time of its discovery, in order that we may properly judge the wells in their behavior, properly treat the wells during their production and properly develop the field at large.

One of the causes of overproduction is the fear that neighboring wells will drain the property if it is not developed rapidly. This fear is well founded in reservoirs of Hydraulic and of Volumetric Control. In these we need co-operation among the various operators. On the other hand, this fear is absolutely unfounded in reservoirs of Capillary Control. Co-operation is unnecessary; single offsets to the adjoining wells are entirely sufficient to prevent drainage; the remaining oil within the interior of the property will rest untouched until the end of time. By means of the principles brought forth in this treatise we shall see the stabilization of the industry. We shall obtain the greatest amount of oil at the least cost only so rapidly as we need it for the market.

San Francisco, California, June, 1928.

Groundwater Hydrology Baker & Conkling "Water Supply and Utilization." Groundwater Hydrology.

10-1. GENERAL.—The term "groundwater" as used herein is taken to refer to that water which exists in the earth between the land surface and the upper zone of rock flowage. This water occupies an important place in the problem of water supply, and in many sections of the West it provides practically the only source from which developments may be made. The underground reservoirs, formed by the water occurring in the interstices of the rocks and soil, afford almost unlimited capacity for cyclic storage; they are provided by nature at no cost to mankind except that of extraction, and have ample protection against evaporation losses. In sections where surface storage is impossible due to lack of available sites, or is prohibitory on account of cost or wide seasonal variation of streamflow, resort must be had to groundwater development.

Such development usually requires a low initial investment and encourages utilization of water supplies in small units. The large capacity of underground reservoir provides holdover storage capacity with ample supply available on demand. This feature and the relatively high operating cost, as compared with gravity systems, make economy in the use of water characteristic of pumping developments.

General Principles of Occurrence of Groundwater.

10-2. Porosity. —All solid material going to make up the surface of the earth is classified in geology by the term "rock" irrespective of its structure, occurrence, or chemical composition, and this term will be used in such connection herein. Groundwater in the earth's surface occurs in the interstices, or open spaces, in rock matter, and that property which rocks have of containing interstices is defined as porosity.[1] The porosity of a material is usually expressed as the percentage of the total volume of the material that is occupied by interstices. It may be dependent upon a number of factors,[1] some of which are:

Shape, size, and arrangement of constituent materials,

Cementation and pressure to which the material has been subjected since deposition.

Table 55.—Porosity of Various Rocks and Soils
(Water Supply Paper 489, p. 10, U. S. G. S.)

Rock	Authority	Number of Tests	Porosity (Per Cent by Volume) Mini-mim	Maxi-mim	Average of Mean
Granite, schist, and gneiss	Buckley [1]	14	0.02	0.56	0.16
Granite, schist, and gneiss	Merrill [2]	22	0.37	1.85	1.20
Babbro	Merrill [2]	1	.....	.....	0.84
Diabase	Merrill [2]	2	0.90	1.13	1.01
Obsidian	Delesse [3]	1	.....	.....	0.52
Sandstone	Buckley [1]	16	4.81	28.28	15.89
Sandstone	Merrill [2]	.....	3.46	22.80	10.22
Quartzite	Merrill [2]	1	.....	.....	.80
Quartzite	Geikie [4]	.....	.....	.....	.21
Slate and shale	Delesse [3]	2	0.49	7.55	3.95
Limestone, marble and dolomite	Buckley [1]	11	0.53	13.36	4.85
Chalk	Geikie [4]	.....	.....	.....	53.00
Oolite	Merrill [2]	8	3.28	12.44	7.18
Gypsum	Geikie [4]	.....	1.32	3.96	2.64
Sand (Uniform)	King [5]	Many	26.00	47.00	35.00
Sand (Mixture)	King [5]	Many	35.00	40.00	38.00
Clay	King [5]	Many	44.00	47.00	45.00
Clay	Geikie [4]	.....	.....	.....	53.00
Soils	U. S. Dept. of Agriculture	Many	45.00	65.00	55.00

[1] Buckley, E. R., Building and ornamental stones (of Wisconsin), Wisconsin Geol. Survey Bulletin 4, pp. 400-403, 1898.

[2] Merrill, G. P., Stones for building and decoration, Appendix.

[3] Delesse, Achille. Recherches sur l'eau l'interieur de la terre; Soc. Geol. France Bulletin, 2d ser., Vol. 19, pg. 64, 1862.

[4] Geikie, Archibald, Textbook of Geology, 4th ed., Vol. 1, p. 410, 1903.

[5] King, F. H., Principles and conditions of the movements of ground water; U. S. Geol. Survey, 19th Annual Report, pt. 2, pp. 209-215, 1898.

Amount of material dissolved by water percolating through the formation,

Amount of fracturing to which the material has been subjected.

10-3. Classification of Rocks According to Distribution of Interstices.[3]—The behavior of water in rocks depends upon the size, relative volume, shape, and distribution of interstices, and rocks may be classified accordingly. The following classification is based upon the uniformity of distribution:

1. Uniform Distribution:

(*a*) Unconsolidated granular rocks.

(*b*) Consolidated granular rocks.

2. Non-uniform distribution:

(*a*) Dense rocks.

(*b*) Fractured rocks—altered by fracturing, solution, etc. Rocks falling in the first class include sand, gravel, clay, silt, and similar unconsolidated deposits; and sandstones, conglomerate and other cemented or otherwise consolidated rocks, where the interstices are fairly uniform throughout the rock mass. In the second class occur such rocks as granite, which is relatively dense and in its unaltered state has a practically negligible porosity; limestone, which may have a fairly large porosity owing to solution channels; and basalt, with a high porosity due to fractures, contraction joints, etc.

In rocks of the first class the behavior of groundwater, the water content, and the yield may be fairly well pre-

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A—Well-assorted sedimentary deposit having high porosity.

B—Poorly-assorted sedimentary deposit having low porosity.

C—Well-assorted sedimentary deposit consisting of pebbles that are themselves porous so that the deposit as a whole has a very high porosity.

D—Well-assorted sedimentary deposit whose porosity has been diminished by deposition of mineral matter in the interstices.

E—Rock rendered porous by solution.

F—Rock rendered porous by fracturing.

(Water Supply Paper 489, U. S. G. S., p. 3)

dicted from knowledge gained from small samples; but in the second class these qualities will vary with the same kind of rock, and for that reason they are much less dependable as sources of water supply.

10-4. Forces Controlling Behavior of Water in Rocks.—Water as it exists in the interstices of rocks is subject to two controlling forces, that of gravity, which tends to draw the water down to lower levels, and that of molecular attraction, tending to hold the water in suspension against the force of gravity in the small interstices within the rock material. Molecular attraction is appreciable only over minute distances, and can act only within the very minute interstices and crevices of the rock mass. When it acts between the molecules of like materials it is termed "cohesion" and between the molecules of different materials it is called "adhesion". It gives rise to the phenomenon known as surface tension or capilary attraction.

Surface[2] tension is that phenomenon which causes a liquid to spread out in a minute film over rock surfaces, and cause drops of a liquid to take on a spherical form. Capillarity is that phenomenon which causes a liquid to rise against the force of gravity through small tubular openings. In the smaller minute interstices in a rock mass, molecular attraction will retain a large percentage of the water occupying the interstices against the pull of gravity; in granular masses made up of small particles the surface area is very great, consequently a large amount of water is necessary to cover the surfaces of these particles. King[3] estimates that the aggregate surface of the particles occupying a cubic foot of loam soil would equal an acre,

but in a cubic foot of clay they would aggregate four acres.

10-5. WATER-YIELDING CAPACITY OF ROCKS.[4]—Even though all of the interstices in a rock are completely filled with water, not all of the water may be extracted. A portion of the water content is under the influence of gravity and will drain out and pass to lower levels, but the balance will stay in suspension, held there by forces of molecular attraction. That water which is controlled by the force of gravity is termed "gravity groundwater," and the percentage of gravity groundwater in a volume of rock is known as the "specific yield," while that percentage which is retained within the rock against the force of gravity is termed the "specific retention". For example, if a rock mass of 100 cubic feet with a porosity of 30 per cent (=30 cubic feet) yields 16 cubic feet of water, its specific yield is 16 per cent, and its specific retention is 14 per cent (30—16=14). It is the specific yield of rock formations that is of particular interest to the student of water supply, as this characteristic determines the volume of the storage capacity existing within the rock mass.

10-6. FACTORS AFFECTING SPECIFIC YIELD AND SPECIFIC RETENTION.[5]—The specific yield of a rock mass is influenced by both the porosity and the size and distribution of the interstices, the latter in granular material varying with the size and arrangement of grains. The porosity of the rock governs the total possible water content, but the size of grain controls the magnitude of molecular attraction between the water and the rock material, and consequently the proportion of water which the rock

will give up against the force of gravity. Figure 109, based upon experiments made by Hazen, shows the influence of size of granular particles upon the specific retention, and emphasizes the marked effect of small sizes of less than 0.5 millimeter, the size of medium sand.

In connection with this phenomenon it has been shown that clay has a porosity approximately equal to that of sand or gravel, but due to the minute size of its grains and resulting interstices, its specific retention is almost equal to its porosity, with its specific yield almost zero. On the other hand, dense rock such as limestone or basalt may have a relatively low porosity with a high specific yield closely approaching the porosity because of the large size of interstices.

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[3] F. H. King, 19th Ann. Rept. U. S. G. S. (1899).
[4] O. A. Meinzer, Water Supply Paper 489, U. S. G. S., p. 50 (1923).
[5] Principles and Conditions of the Movements of Groundwater, 19th Annual Rept., U. S. G. S., Part 2 (1899).

SUMMARY OF OPERATIONS

California Oil Fields

MONTHLY CHAPTER. FOURTEENTH ANNUAL REPORT

OF THE

STATE OIL AND GAS SUPERVISOR

ISSUED BY

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF OIL AND GAS

Vol. 14 SAN FRANCISCO, CALIFORNIA, JUNE, 1929 No. 12

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E. H. MUSSER, Coalinga

PREFACE

Publication of the report of the State Oil and Gas Supervisor in monthly installments commenced with April, 1919.

The report carries a digest of all decisions made by the supervisor, during the month, in response to notices filed by operators. Notices of all proposed well operations are required by law.

Special articles dealing with the various phases of oil field operations also appear in the report. These articles present the results of observations of engineers of the Division of Oil and Gas. Short articles of a suitable nature, written by operators or outside engineers, are also accepted for publication. A complete list of all special articles published to date is given in each number of the monthly "Summary of Operations," and an alphabetical index of these articles is given in No. 12 (June) of each volume.

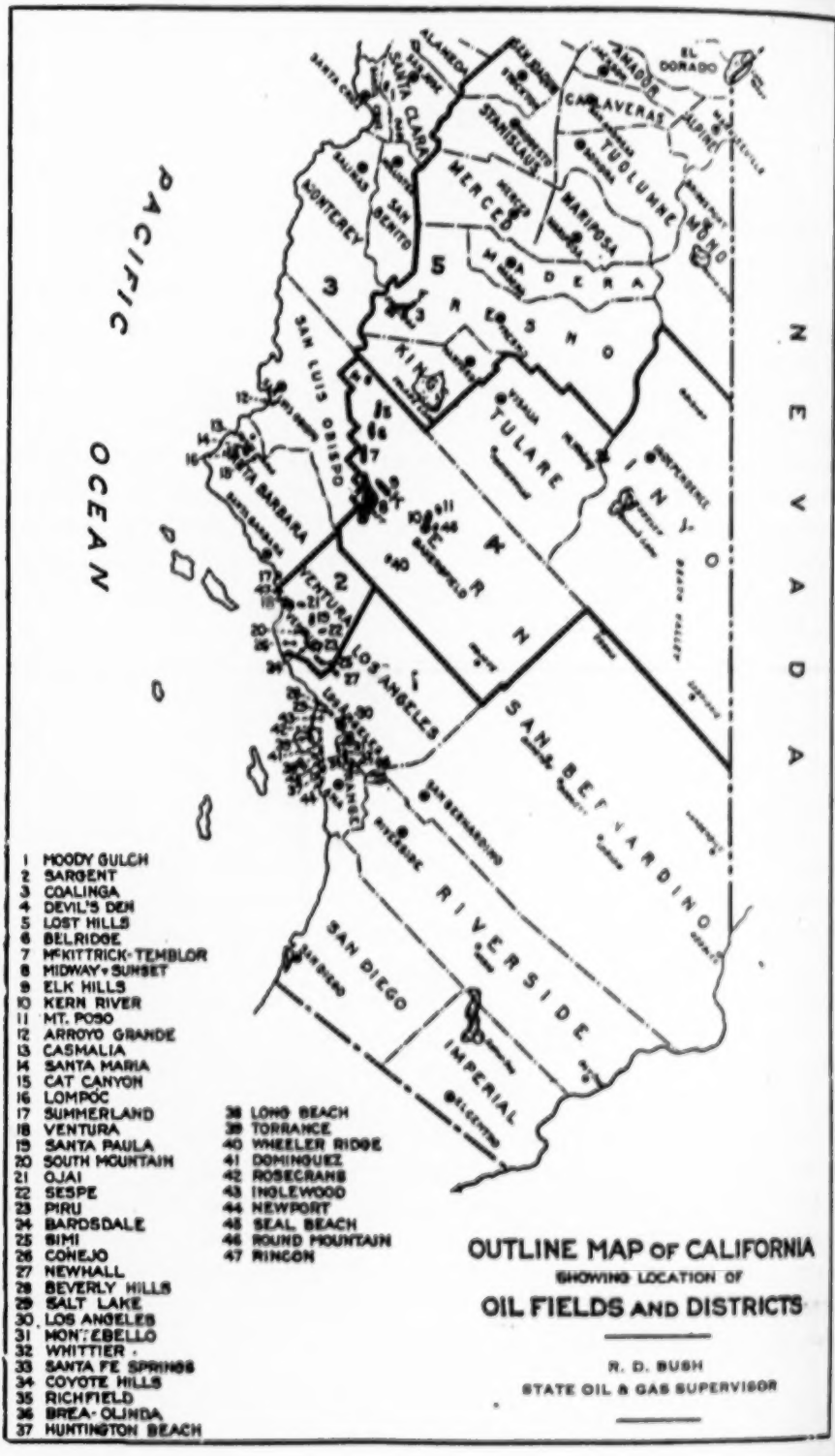
Prospecting operations in unproved areas, or for undeveloped formations within proved areas, will not be reported in full until after completion of the work if the operator so requests. The law provides for such procedure in that certain wells may be designated by the State Supervisor as "prospect wells."

The Division of Oil and Gas aims to serve the oil operators of California by furnishing them with the best information obtainable by state-wide scientific observation. The purpose is to have all wells drilled and maintained in accordance with the most approved methods. The desired end can only be attained by careful study and attention to many details.

Branch Offices of the Division, maintained in the various oil fields, afford the oil operators an opportunity promptly and informally to avail themselves of the service which is at their disposal.

The monthly report is mailed to all assessment payers, to the legal agents of operating concerns, and to other interested parties.

Errors appearing in this publication will be corrected as soon as brought to the attention of the Supervisor. All readers are invited to assist the Division by calling attention to errors and also by giving suggestions which might add to the usefulness of the monthly "Summary of Operations."



OUTLINE MAP OF CALIFORNIA
SHOWING LOCATION OF
OIL FIELDS AND DISTRICTS

R. D. BUSH
STATE OIL & GAS SUPERVISOR

CROOKED HOLES

By Paul J. Howard*

Introduction.

The success or failure of wells drilled to depths greater than 4000 feet often depends upon the inclination and direction the holes have taken. This is especially true in fields having strata lying at steep angles, such as the Long Beach oil field. In this field, in a number of instances wells have actually come in contact with each other, and in other instances holes have drifted so close together that mud from a drilling well flowed from a producing well. At such times it becomes necessary to shut in the producing wells, sometimes under back pressures, until strings of casing are cemented in the drilling wells. Some of these producing wells, when again permitted to flow, never regain their former rate of production. There are cases where holes have flattened out so much that bailers could not slide to bottom, although no difficulty was encountered with the drill pipe.

Usually straight vertical holes should be drilled in order to obtain the most satisfactory wells. A straight vertical hole saves casing and wear on drilling equipment. It may often save time in drilling, due to the fact that it may not have to be drilled as far as a crooked hole to reach the productive measures. Straight holes simplify the problems of correlating and obtaining uniform water shut-offs, and they obviously save wear on pumping equipment and increase its efficiency.

It is the purpose of the writer to present various methods which have been found helpful in drilling straight holes, to show the relationship of crooked holes to correlated depths, the importance of surveys, to describe the various devices used in California for determining the inclination, or inclination and direction, of rotary drilled holes, and to present charts to be used in conjunction with surveys for the purpose of correlation.

The writer is indebted to the owners of the various devices described herein, for their kindness in giving information in regard to their instruments, and especially to Mr. Alexander Anderson in furnishing various tables and diagrams.

Straight Holes.

A number of suggestions for drilling straight holes have appeared in recent articles on the subject of crooked holes. The committee on drilling practice of the American Petroleum Institute under the chairmanship of Mr. Melbert Schwarz, engineer of Rio Bravo Oil Company at Houston, Texas, recently sent out questionnaires to one hundred and fifty operators in that district in regard to crooked holes and straight-hole drilling practice. The information and opinions obtained were printed in the *Oil Weekly* of September 20, 1929, and were as follows, in order of their rated importance:

* Inspector, Division of Oil and Gas.

To drill a straight hole—

1. Use less weight on the bit and use a method of weight control.
2. Use less pump pressure and a slower rate of circulation.*
3. Use increased rotary speed, making suitable allowances for the type of formation drilled. This will tend to prevent the drill pipe from wobbling.
4. Carefully check the weight and suspension qualities of the mud.
5. See that the derrick and rotary are properly aligned at the start and remain so during the drilling of the well. Uneven settling of the foundations may throw out the alignment.
6. Start the hole straight. Use guide rings and turnbuckles to hold the kelly in a vertical position. Use a spirit level frequently as a check.
7. Employ drillers sold on the straight-hole idea.
8. Use reamers * and lace joints or long drill collars on the bottom of the drill pipe.
9. Use heavy rigid drill pipe.
10. Use the proper size of machinery.
11. Avoid "rathole" unless the drill string is equipped with reamers to guide the "rathole" in the center of the well bore.

The following information was also obtained by this questionnaire:

It is not satisfactory to increase the weight on a dull bit. Replace it.

When drilling through steeply dipping beds with the weight held up and using a high speed of rotation, there will be a tendency to dig into the inclined formations rather than drift down dip.

If the mud is too thin, there will be a tendency to wash out soft formations and the bit will wobble down the top of the next hard formation. This will be especially true if too much weight is carried.

When a cement plug is drilled out below the casing, the weight should be held up to prevent drilling alongside of the plug. A guide may be used to advantage when drilling out a plug.

If the size of a hole is reduced without the use of a guide, there will be a marked tendency to crook the hole at that point.

Mr. Robert R. Robinson believes that the following five factors affect the straightness of drilled holes to a marked extent:

1. The formation—hard and soft strata alternating.
2. The kind and condition of the cutting tools—bit and reamers.
3. The size of drill pipe and drill collars.
4. The condition of the mud.
5. The feed of the bit.

Mr. Robinson suggests that more or larger fluid holes in the bit be used rather than a slower circulating rate in order to reduce the hydraulicking action of the mud fluid.

Mr. H. H. Jones, of Continental Oil Company, believes that the problem of drilling straight vertical holes is not as difficult as most

* These recommendations are open to question.

operators maintain. His conclusion is that the drilling of vertical holes depends solely on the force of gravity. All devices constructed to make straight holes should be designed with this principle in mind. Mr. Jones recommends the use of a fishtail bit, whenever it will drill the formation, on the bottom of a very long heavy drill collar. The drill collar concentrates the weight at the bottom of the string of pipe and gravity tends to hold it vertical. He states: "The fishtail bit should be true and straight both flatwise and edgewise. The slush holes should point down the middle of the blade. The body should not be much larger than the drill collar. The cutting blades should be the largest part of the bit and both the bottom edge and the side edges should be comparatively sharp. The side edges should be about 8 inches long and be faced with the best possible hard metal, ground to an actual edge." The tendency is for the drill collar and bit to hang vertically. In case it should not always be in this position, the side edges of the bit would cut the formations until the hole would finally become vertical. A fishtail bit requires less weight for drilling than most other bits. This permits the drill pipe to rotate with less bending.

Crooked Holes.

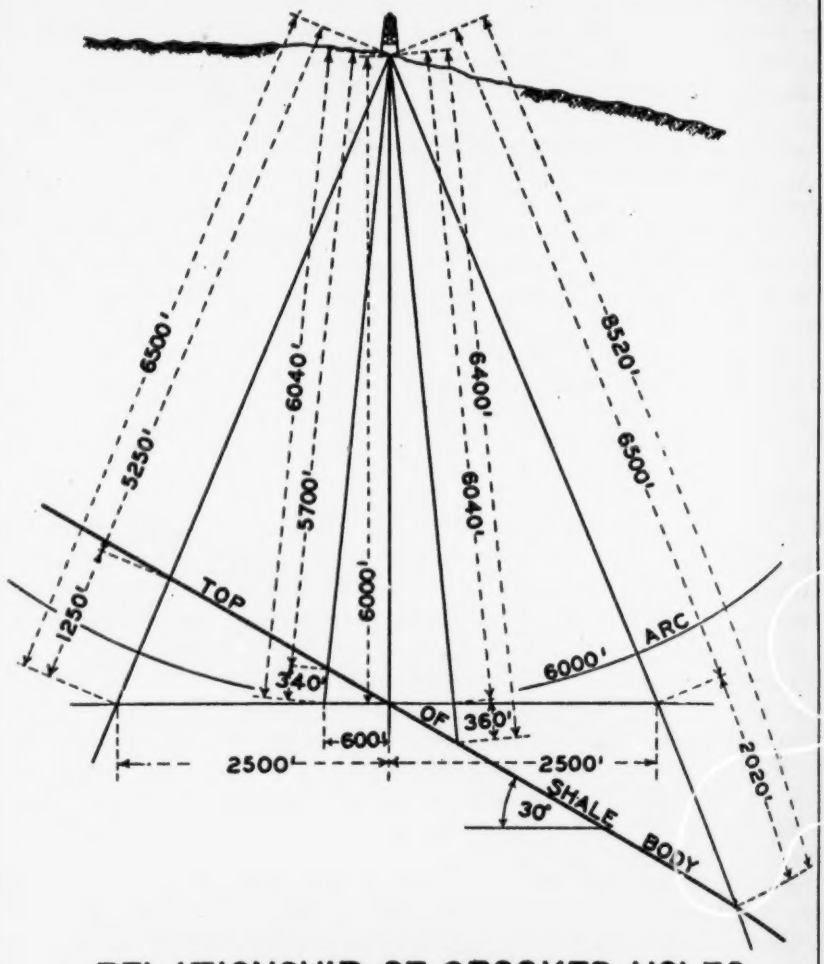
The Long Beach oil field probably holds the world record for crooked holes. The subsurface contours of this field show the strata on the southwest flank of the structure to be lying at an angle of approximately 30 degrees from the horizontal, while the extreme western end of the field is nearly flat.

In the case of wells drilled to less than 3000 feet in stratified structures, it is usually quite simple to choose the cementing depths for casings by correlation. In such cases, no great amount of coring is necessary, because usually such wells are nearly vertical. However, where wells are deep and there are no satisfactory marker strata, it is not so easy to determine the cementing points and tops of the productive measures. Especially is this true when the strata are greatly inclined. If deep wells were straight and vertical, the problem would be simplified. Since they are not, and most wells drift considerably, the use of correlation, in its simplest form, becomes practically useless for determining the proper cementing depths. In such cases, extensive coring becomes the rule. Without definite marker strata, the conclusions drawn from coring may be entirely erroneous.

Examples

Suppose it is assumed that a well will be drilled on a structure having strata lying at an angle of 30 degrees from the horizontal. A water string is to be cemented in a 20-foot shale body lying at 6000 feet below the derrick floor. This stratum overlies about 500 feet of oil sand and shale. Assume that the depth of the shale body has been determined by corrected correlated data on surrounding wells. The operator may say that coring will be commenced at 5900 feet. In all probability the hole will drift away from vertical. It is possible that the hole may drift up structure, down structure, along the structure, or in an intermediate direction. The well may drift as much as 2500 feet horizontally in 6000 feet vertical depth.

FIGURE 1



RELATIONSHIP OF CROOKED HOLES
—TO—
AN INCLINED STRATUM

ACCOMPANYING PAPER "CROOKED HOLES"

—BY—

PAUL J. HOWARD

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF OIL & GAS

R.D. BUSH, STATE OIL & GAS SUPERVISOR

—SCALE—

0 1000 2000 3000 FT.

TABLE I

HORIZONTAL DRIFT & VERTICAL DEPTH PER 100 FEET OF MEASURED DEPTH AT DIFFERENT INCLINATIONS FROM VERTICAL

— BY —
ALEXANDER ANDERSON

ACCOMPANYING PAPER "CROOKED HOLES"
— BY —
PAUL J. HOWARD
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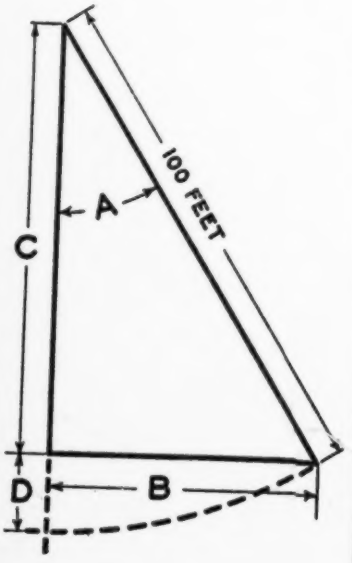
A INCLINATION OF HOLE FROM VERTICAL	B HORIZONTAL DRIFT PER 100 FT. OF HOLE	C VERTICAL DEPTH DRILLED PER 100 FT. OF HOLE	D LOSS IN VERTICAL DEPTH PER 100 FT. OF HOLE
0°	0.0	100.0	0.0
5°	8.7	99.6	0.4
10°	17.4	98.5	1.5
15°	25.9	96.6	3.4
20°	34.2	94.0	6.0
25°	42.3	90.6	9.4
30°	50.0	86.6	13.4
35°	57.4	81.9	18.1
40°	64.3	76.6	23.4
45°	70.7	70.7	29.3
50°	76.6	64.3	35.7
55°	81.9	57.4	42.6
60°	86.6	50.0	50.0
65°	90.6	42.3	57.7
70°	94.0	34.2	65.8
75°	96.6	25.9	74.1



Suppose, first, that the hole drifts up structure. The cores show gray sand and shale from 5900 to 6000 feet, drill pipe measurements, with no shale bodies over 10 feet thick. The well is surveyed and the bottom is found to be 2310 feet horizontally, up structure from the mouth of the hole. If the hole lay in a straight line from the surface to this point, the bottom of the hole would be about 230 feet below the body of oil sand and about 730 feet below the shale body desired. (See Fig. 1.) These values may be discounted somewhat, as the hole would probably take a curved path from the mouth to this point.

Mr. Alexander Anderson compiled the results of surveys of 255 rotary drilled holes made during the years 1925 to 1928, inclusive. This table showed that the average horizontal drift of a 6000-foot hole was about 600 feet. However, he believes that the actual average for all wells of this depth would be about 25 per cent less than his average because of the considerable number of unsurveyed comparatively straight holes. Since 1928 Mr. Anderson has surveyed and compiled the table of results of surveys of the 183 rotary drilled holes, and these results are shown in Table 2. Prior to 1928 the amount of drift of a rotary hole and the costly results in many instances were little realized, but since that time there has been a very material improvement in the verticality of oil wells, and this is clearly shown in Table 2 where the average horizontal drift of a 6000-foot hole is about 290 feet. .

For purposes of illustration, using Mr. Anderson's average drift of 600 feet per 6000 feet corrected depth, and assuming the drift is directly up structure, we find the bottom of the hole at 6000 feet, drill pipe measurement, about 280 feet below the shale body desired, or about 180 feet in the oil sand when coring was started. A thinner body of oil sand could have been passed up entirely.

Suppose, next, that the hole drifted 2310 feet down structure as determined by a survey at 6000 feet. In this case, the hole would have to be drilled about 2520 feet farther, that is, to 8520 feet, to reach the shale body desired. Actually, this distance would be greater, due to the fact that the hole would probably be curved. Suppose that a shale body had been encountered at about 6000 feet and a string of casing had been cemented. What would have been the result? Probably nothing but water sand. The well next to this one might have been cemented at about the same depth and become an excellent producer. Similar cases do occur. Suppose, now, we use Mr. Anderson's average drift of about 600 feet per 6000 feet corrected depth. This drift down structure would place the bottom of the hole at 6000 feet, about 360 feet above the shale body in the line it was traveling. Actually, this distance would be greater because of the curved path of the hole. It can readily be seen that the wrong shale body might be used in this 360 feet with very discouraging results.

Next, assume that the hole drifted along the structure, but neither up nor down. First, assume that a survey at 6000 feet revealed a drift of 2310 feet horizontally. In this case, the hole would have to be drilled about 500 feet farther before reaching the shale body. Using the average 600-foot drift per 6000 feet corrected depth in the same direction, the hole would reach the shale body at about 6040 feet provided the hole was drilled in a straight line from top to bottom. Both

TABLE 2—NOVEMBER, 1929

DRIFT AND INCLINATION OF OIL WELLS

Some Data From Underground Surveys of 183 Rotary Drilled Holes in California, 1,818,906 Feet of Hole and 11,856 Individual Survey Readings

By Alexander Anderson

Number of holes	A Depth in feet (measured depth)	B Horisontal distance from mouth to bottom of hole (in feet)			C Inclination of hole from vertical (in degrees and feet per 100)			D Amount of drift from vertical (in feet)		
		Maximum	Minimum	Average	Maximum	Minimum	Average	Maximum	Minimum	Average
183	500	30	0	5.8	7° 30′ 13.1 ft. per 100	0° 00′	1° 23′ 1.8 ft. per 100	31	0	6.9
183	1,000	130	0	19.4	12° 45′ 22.1 ft. per 100	0° 10′ 0.3 ft. per 100	2° 14′ 3.9 ft. per 100	132	5	23.6
178	2,000	531	3	56.2	29° 00′ 48.5 ft. per 100	0° 15′ 0.4 ft. per 100	3° 24′ 5.7 ft. per 100	540	15	70.2
170	3,000	730	7	103.5	29° 00′ 48.5 ft. per 100	0° 20′ 0.6 ft. per 100	4° 19′ 5.7 ft. per 100	738	21	135.4
155	4,000	717	7	141.5	22° 00′ 37.5 ft. per 100	0° 20′ 0.6 ft. per 100	5° 22′ 9.4 ft. per 100	796	28	203.4
124	5,000	831	3	211.9	28° 00′ 46.9 ft. per 100	0° 30′ 0.9 ft. per 100	8° 03′ 14.0 ft. per 100	835	101	304.7
79	6,000	844	33	291.2	27° 00′ 45.4 ft. per 100	1° 00′ 1.7 ft. per 100	8° 50′ 15.4 ft. per 100	985	129	422.5
52	6,500	1,033	35	324.6	27° 00′ 45.4 ft. per 100	0° 30′ 0.9 ft. per 100	8° 48′ 15.3 ft. per 100	1,081	143	463.2
32	7,000	900	60	372.8	32° 30′ 55.2 ft. per 100	1° 30′ 2.6 ft. per 100	11° 54′ 21.9 ft. per 100	1,100	308	535.0
10	7,500	769	186	474.1	32° 00′ 53.0 ft. per 100	6° 20′ 11.0 ft. per 100	18° 48′ 31.2 ft. per 100	1,012	377	695.3
4	8,000	1,035	349	602.7	31° 00′ 51.5 ft. per 100	10° 15′ 17.8 ft. per 100	20° 58′ 35.8 ft. per 100	1,130	466	730.0

Explanation of Terms—

"B" is the horisontal distance between a vertical line through the mouth of the hole and a vertical line to the hole at the listed depth.

"C" is the inclination from vertical at the listed depth.

"D" is the total drift from vertical down to the listed depth.

In the case of a well drifting in the same direction from mouth to bottom "B" and "D" would be equal.

would increase this distance. Holes drifting between the directions of dip and of strike of the strata would have values falling between those given.

It can be seen readily that when holes drift, even to the average extent, cores may indicate a gray sand at a depth where oil sand was expected. Also, cores taken from about the proper estimated depth may seem to indicate that the proper shale body for landing casing has been reached, when in reality the shale body cored may be several hundred feet from the proper stratum. Crooked, unsurveyed holes easily account for many apparent inconsistencies in productive areas. It becomes almost impossible to drill successful wells in fields such as the Long Beach field without the use of surveys.

Some operators rely to some extent upon the dip of the strata as shown in the cores. If a hole is drilled straight down into a structure having a 30-degree dip the cores will show 30-degree dips. If the hole drifts down structure the dips will appear to be over 30 degrees. If it drifts directly up structure the dips will appear to be less than 30 degrees. If it drifts directly along the structure, that is, along the strike of the strata, the cores will show dips of 30 degrees or more, depending upon the extent of the drift. There are, then, points between the line of strike and the line of dip up structure where the cores would show 30-degree dips without the hole being straight. Since holes do not usually go in straight lines, it is possible for them to drift a great distance down structure, or up structure, and then change direction. Cores taken after such a change could be very misleading. The best way to determine the position and direction of a well is by the use of acid bottles, coring, surveying, and correlation, followed by a comparison of results.

Oil Well Surveying Instruments.

The need for surveys has become more urgent since wells have been drilled to depths of over 4000 feet. The demand for surveys has resulted in much experimental work and has brought many instruments into this field. The writer does not believe that there are any instruments or methods of surveying oil wells that can be depended on for absolute accuracy under all conditions and at all times.

Any method by which a complete survey is made must provide means for determining the amount of inclination of the hole at selected points and, in addition, the direction of this inclination. The pendulum swinging from a ball and socket joint, the level bubble, and the action of gravity upon a freely moving object, serve as the usual means for obtaining the amount of inclination of a hole. The orientation of drill pipe into the hole and the magnetic compass serve as the usual methods of obtaining the direction of inclination of a hole. To the best of the writer's knowledge, the gyroscope has never functioned successfully in any oil well surveying instrument. The methods of surveying employed by Mr. Olsen and the Trojan Exploration Company are entirely different from the others and will be discussed later.

There is no need to comment on the methods used for determining the angular inclination of a well, as all of these methods should be quite successful. However, something should be said in regard to the

methods of determining the direction of dip. The proponents of the methods involving the orienting of drill pipe into the hole have little faith in methods involving the use of the magnetic compass. They state that the needle will be affected by sidetracked tools or pipe, by the casing in which it is run—if run in casing—by the drill pipe to which the instrument is attached, by tools or casing in other nearby wells, and by scattered particles of steel left in the walls worn or broken from the drill bits. The proponents of the magnetic compass claim that unless the metal above described is quite close to the compass, it will have no effect. They state that the methods involving the use of oriented drill pipe may be in error because some torque may be in the drill pipe underground which is not transmitted to the surface where it can be measured. In at least one case three different survey methods were used for one well and each showed the bottom of the hole in a different quadrant of the compass.

It should not be supposed that because surveys do not always check out they are usually wrong. In fact, it may be said that some surveys are nearly always correct. The information obtained from surveys, acid bottles, and cores, forms the best available information about the amount of inclination and the direction of the inclination of a well and should be accepted as such.

The following instruments or devices are used in California for determining the angle of inclination and direction of inclination of oil wells. The writer has listed all of the methods with which he is familiar, but it is probable that others will have been developed by the time this article has gone to press.

Instruments and Methods for Determining the Angles of Inclination Only.

Acid Bottle

Glass bottles, partially filled with fresh hydrofluoric acid and water, are commonly used for determining the inclination of oil wells. Their use depends upon the chemical property of hydrofluoric acid to etch glass. Bottles are run into the wells in such a manner that their axes are parallel to the casing or to the walls of the well. They are permitted to rest at the proper depth for 15 or 20 minutes. By the end of that time, the acid will have attacked the glass below the fluid so as to leave an etched line in a horizontal plane around the bottle at the surface of the acid. After time has been allowed for etching, the bottle is removed from the hole. The inclination of the hole is equal to the vertical angle between the plane through the etched line and the axis of the bottle. Many times considerable difficulty is experienced in reading the angle of inclination because of a "fuzzy" line caused by the meniscus at the top of the acid. This difficulty may be eliminated to a great extent by pouring very light lubricating oil on top of the acid, thus destroying the meniscus. The greater the diameter of the bottle, the more accurately can the angle be read. The action of the acid on the bottle while removing it from the hole usually is not sufficient to destroy the etched line.

Acid bottles may be run in bailers, on the bottom of drill pipe, or in "go-devils" which are dropped, and pumped if necessary, through drill pipe.

Bottles must be placed in tight containers to prevent the pressure in deep holes from breaking them or forcing the rubber stoppers into them. Bottles are usually fitted into recesses only slightly larger than themselves. They are often seated on rubber sponge, and wrapped with rubber bands, to eliminate breakage due to shock. When "go-devils" are used, additional methods should be employed to take up the shock resulting from striking the tool joints and bit.

One particular type of "go-devil" is constructed as follows: A section of pipe about 10 or 12 feet long is provided with a shock absorber at the lower end and a screw connection for the acid bottle container at the upper end. The shock absorber consists of a plunger projecting about 6 inches below the body of the "go-devil." This is followed by a spring for absorbing the shock as the lower end of the plunger strikes the tool joints and bit. The lower end of the plunger is tapered and has about the same maximum diameter as the body of the apparatus. Two slots are cut in the head of the plunger to permit circulation when it strikes the bit and to allow the fluid to run out of the drill pipe as it is pulled from the hole. The body of the "go-devil" is perforated to permit access of the fluid. The container for the acid bottle has the same diameter as the body of the "go-devil," and has a recess just large enough for a ¾-inch by 2½-inch bottle with a piece of rubber sponge above and below it. The top of the acid bottle fitting consists of a hexagonal headed plug, which, when screwed up, closes the acid bottle container and secures it to the body of the "go-devil."

"Go-devils" are run just previous to pulling the drill pipe. While the acid is acting, the drill pipe should be raised or lowered, without rotation, about every three minutes to prevent it from sticking. In certain cases "go-devils" have been found hung up in the drill pipe, but when properly designed this should not occur.

Elliott Drift Indicator

The Elliott drift indicator determines the inclination of a hole by use of a plumb bob which hangs in an oil bath. The plumb bob is attached to a rigid arm extending downward from a ball and socket joint, located on the bottom of a plunger. Just below the plumb bob is a semihard rubber disc shaped to form a section of a sphere with a radius equal to the distance from the point of the plumb bob to the ball and socket joint. Concentric rings are inscribed about its center at intervals equivalent to 2-degree inclinations. When the drill pipe has been run to the desired depth, the pumps are started and the pressure of the fluid forces the plunger down. As a result, the point of the plumb bob is forced into the disc. Lugs in the side of the instrument prevent the plunger from rising and thus hold its point in the disc until the instrument is dismantled. The position of the impression of the bob indicates the inclination of the hole.

The instrument is placed in a special section in the drill stem which has the same outside diameter as the tool joints, and provides for unrestricted circulation around the instrument. This instrument may be placed at any desired point in the drill stem and drilling may continue as long as desired after obtaining the impression.

Only one reading may be taken with each round trip of the drill pipe. This instrument was devised primarily to replace the acid bottle, which can not be left in the hole while drilling is in progress.

Hercules Crooked Hole Detector

The Hercules crooked hole detector provides a quick method of locating crooks in a hole and of giving the inclination, but does not provide means of determining the direction of the inclination. The instrument is run into the hole from a reel on a truck especially provided for the purpose and may be run in open hole. In case it should become stuck, the line can be pulled loose directly above the case and the instrument easily sidetracked.

This instrument is provided with a pendulum which swings from a ball and socket joint with an arm extended above the joint. It can move in any direction. The top of the extended arm is provided with a point which is held in contact, by a light spring, with a concave spherical surface consisting of concentric rings of brass wire imbedded in an insulating medium. Each ring is connected to an electrical resistance. The wires are spaced so that each wire represents an angular dip of 1 degree. Angles up to 20 degrees may be read. The apparatus is placed in a steel case and is completely immersed in transformer oil to prevent collapse.

The instrument is run into the hole on a duplex insulated steel line. An electric current at 5 volts is passed from a storage battery through the lines and instrument to a millimeter. The amount of current flowing is dependent upon the resistance thrown into the circuit by the instrument in the hole, and this in turn is dependent upon the angle of inclination of the hole. The scale on the millimeter is graduated to read in degrees of inclination. The inclination at any point can then be read at the surface as the instrument is lowered in the hole.

Devices Used in Conjunction With Oriented Drill Pipe.

Alexander Anderson Survey Instrument

Alexander Anderson is the pioneer oil well surveyor of California, and he has achieved a remarkable reputation for good work. Patents on his surveying instrument and method of orienting drill pipe into the well have been applied for, and he does not care to divulge the construction of his instrument until the patents have been secured.

However, it is known that photographs are taken every 4 minutes and 10 seconds by clock control, and that records are made in these photographs which indicate the dip of the hole. Eighty-eight photographs may be taken with one run of the drill pipe. Five independent records are made on each photograph which precludes the possibility of accepting the result of one erroneous reading. Vertical angles can be recorded up to 60 degrees from vertical. One photograph is usually taken for each stand of drill pipe run in the hole. Mr. Anderson provides facilities for any operator to test the accuracy of the instrument for himself.

The instrument is attached to the bottom of the drill pipe. The direction in which the reference point of the instrument lies is determined

by use of a sighting device placed in the bottom of the instrument case. Two clamps are attached to the drill pipe near the top of each stand before it is lowered into the well. The lower clamp is circular and graduated in degrees around part of its circumference. The top clamp has a horizontal circular hole through it, forming a socket, at a tangent to the drill pipe. A sighting device is fitted into this socket. The device consists of a piece of ¾-inch pipe about 3 feet long with front and rear sights attached. The front sight is formed by a long vertical wire, and the rear sight consists of a vertical row of small holes.

The sight is aligned with a previously designated distant object, and a row of stakes provided for emergencies, and the clamp is then tightened. A level bubble is provided for placing the sighting device in a vertical position. The lower clamp may be set with its zero reading at a pointer which projects from the upper clamp. This is rarely done except when setting whipstocks. The sighting device is then withdrawn and the drill pipe lowered. After the next stand is made up, another sighting device, kept on the derrick floor, is fitted into the same socket.

Along the side of the derrick nearest the distant object, a number of ¼-inch slats are laid in line, end to end, on suitable planks. A zero point on the slats is marked in line with the distant object and the sight bar hole. After lowering each stand of pipe, and placing the sighting device in the hole, a punch target, moved along the slats by a workman, is brought into the line of the sight and a mark is made on the slat. The marks are properly numbered. Knowing the perpendicular distance of the slats from the drill pipe, and knowing the distance along the slats from the zero point to the punch mark, the angle through which the drill pipe has rotated can be calculated. The distances of the various punch marks from the zero point are measured, and the angles calculated after leaving the derrick. When desirable, instead of using the slats, the upper clamp can be loosened and the bar sighted on the distant point. The angle turned by the sighting device is then read on the lower clamp.

The drill pipe is oriented into the hole in order to determine the direction of the reference point of the instrument at the time each photograph is taken. Thus, the photographs give the amount of inclination and the direction of inclination as measured from the reference point of the apparatus and the orienting calculations give the direction of the reference point at the corresponding positions in the hole.

Jack Johnson Instrument

The Jack Johnson instrument is constructed and operated in a manner similar to that described later as the Pollard and Bonner instrument and therefore will not be discussed here.

R. P. McLaughlin Clinograph

This clinograph operates on the plumb bob principle for determining the angle of inclination of a hole. The direction of inclination is obtained by orienting the drill pipe into the well. Two plumb bobs, moving in vertical planes at a right angle to each other, are attached by suitable mechanisms to two corresponding styluses which draw red

and blue curves on a continuous moving chart. The chart is ruled lengthwise with a series of light lines, representing one-foot intervals, and a heavy line is drawn at the central position of the paper. The chart is ruled vertically at intervals representing one minute of time. Clockworks, synchronized with a chronometer used above ground, wind the chart on a roller at the proper speed.

Assuming that the red line indicates the amount of inclination in a vertical north and south plane and the blue line indicates the amount of inclination in an east and west vertical plane, the red line, if above the central line, indicates inclinations to the north, and if below the line, inclinations to the south. The blue line, if above the central line, indicates inclinations to the east, and if below, inclinations to the west. Any inclinations between these directions are shown by components in two of the above directions. The vertical divisions on the chart indicate the distance, in a north, south, east, or west direction, of the bottom of the drill pipe from the top of the bottom stand. The deviation of the bottom of the drill pipe from a vertical line through the mouth of the hole is actually the algebraic sum of the deviations recorded down to that depth.

When the instrument is run in the hole, the north or zero point of the instrument does not remain in that direction, due to the rotation of the drill pipe as it is lowered into the hole. However, its position is determined for each stand of pipe by measuring its rotation. By calculating the horizontal angle between the zero point in the instrument and true north, the direction of inclination may be readily plotted.

The instrument, in a brass case, is fitted into a blunt-nosed steel cylinder which is attached to the bottom of the drill pipe. Circulation holes are provided near the top of the cylinder. The drill pipe is oriented into the hole in a manner somewhat similar to that used by Alexander Anderson. Two sighting devices are pointed at a marker located at some distance from the derrick. One sight remains stationary, and the other, attached to the drill pipe, may turn. The number of degrees through which it turns is measured for each stand of drill pipe run into the hole. Mr. McLaughlin claims there is no torque in the drill pipe below ground that is not transmitted to the surface where it can be measured.

Oil Well Surveying Company of California Instrument

The instrument of Oil Well Surveying Company of California takes photographs of an object, the position of which at any time is dependent upon the action of gravity. The company does not wish to disclose the mechanical details of this instrument. The position of the object is always on the low side of the hole. The direction of dip of the hole is in a line through the object to the center of the photograph. The position of the object in a vertical hole is at the center of the photograph and the amount of displacement of the object from the central position is a measure of the angle of inclination (from vertical) of the hole. The position of the zero mark in the photograph with respect to north is obtained by orienting the drill pipe into the hole. This instrument

measures vertical angles up to 60 degrees. Every four minutes a clock makes electrical contacts which cause the film to be turned and a light to appear. Dry cells provide the necessary electric power. Three hundred and fifty photographs can be taken before removing the instrument from the well.

In order to read the photograph accurately, the figures are magnified by the use of a moving picture projector, and the readings are made from the screen upon which the image is thrown. A test stand is provided in which the instrument may be placed for checking the photographic readings against a measured angle set off on the stand.

The instrument, housed in a steel case, is attached to the bottom of the drill pipe, a mark on the case indicating the position of the zero mark in the instrument. Its direction is determined by use of a transit. The pipe is then oriented into the hole by attaching a surveyor's transit to the top of each stand of drill pipe as it is lowered into the hole. Before lowering the pipe, the transit is sighted on a point more or less distant. When the stand has been lowered, this instrument is again sighted on the same point. The angle through which the telescope has turned is a measure of the rotation of the pipe. The algebraic sum of the twists, right and left, indicates the position of the zero line in the oil well surveying instrument. Two plumb lines, in line with the transit, hung from the top of the derrick, serve as additional orienting sighting points.

Pollard and Bonner Instrument

The Pollard and Bonner instrument makes use of the plumb bob principle for determining the amount of inclination of wells. The direction of inclination is determined by orienting the drill pipe into the hole. A very large plumb bob, hanging from a universal joint, is attached to two suitable mechanisms, which in turn are connected to two styluses. The two mechanisms move so as to resolve the movement of the plumb bob into two motions at a right angle to each other. The styluses record these movements on a moving strip of paper which is wound up by an electric motor driven by dry cell batteries. The drill pipe is oriented into the hole in such a manner that the plane of the moving chart is held in an east and west direction. A fixed stylus draws a blue line near the edge of the paper. The stylus showing the east and west inclination draws a black line and the one showing the north and south inclination draws a red line. The blue line is used as the reference line, but the zero deflection position is at a known distance from the blue line. A special scale has been devised to read the inclinations recorded by the styluses. They are read directly in feet per stand of drill pipe in an east or west direction, and in a north or south direction. The true inclination is the resultant of these two. The wavy sections, in the lines drawn, indicate the times when each stand of drill pipe was lowered into the hole. Straight lines are drawn while the drill pipe is held in the slips. In order to indicate satisfactorily the proper stands of pipe, the drill pipe is left in the slips an extra long time before running each tenth stand of pipe. This results in the drawing of conspicuously extra long straight lines.

When making the survey, the instrument, in a brass case, is fitted into a steel pipe. A plug is screwed into the bottom of the pipe. The top of the plug is cut by a horizontal notch, into which fits a bar on the bottom of the instrument case. This bar represents the north and south direction of the instrument. In the bottom of the plug, directly below and parallel to the notch, a sighting hole has been drilled. The drill pipe is started into the hole with the sighting hole in a north and south direction. An aiming point is placed at about 600 feet from the derrick. A clamp is fixed to the top of the first stand of drill pipe. This clamp is provided with a sighting bar which moves horizontally about a pin through the clamp. A telescope is attached to this sighting bar. With the sighting hole at the bottom of the pipe in a north and south direction, the telescope is sighted on the aiming point and the sight bar is clamped in position. The telescope is then removed and the stand of drill pipe lowered into the hole. When the next stand has been made up, a telescope on the derrick floor is attached to the clamp now above the rotary table. The drill pipe is rotated sufficiently to bring the line of sight of the telescope on the aiming point. Another clamp is then fixed to the top of the new stand of drill pipe, and the process repeated. It is assumed that whatever torque is given the drill pipe at the surface will be transmitted, in an equal amount, to the bottom of the drill pipe, and thus preserve the orientation of the instrument itself.

Spherical Oil Well Surveying Company Instrument

The Spherical Oil Well Surveying Company instrument makes use of the plumb bob principle for determining the inclination of the hole from vertical. Oriented drill pipe is used for determining the direction of the inclination. Two weights, operating on the plumb bob principle, are connected to two styluses by suitable mechanisms. The weights move in vertical planes at a right angle to each other and thus the inclination of the hole at all points is resolved into inclinations in vertical planes at a right angle to each other. The record charts consist of two hemispheres with the convex sides down. These hemispheres retain a horizontal top surface by the use of the four-point suspension principle. Spiral lines are drawn around each hemisphere, starting at the top. The amount of deviation of the styluses from these lines is a measure of the inclination of the hole in the corresponding vertical plane. The hemispheres are graduated from the top edge to bottom with time interval lines, corresponding to lines of latitude. A clock mechanism, synchronized with a clock at the surface, drives each stylus in the path about the hemisphere. A continuous record is made as the drill pipe is lowered into the hole.

The pipe is oriented into the hole by the use of a special sight mounted on the top of the drill pipe. Below the sight is a graduated circle on which the rotation of the drill pipe is measured. The sight in the derrick is brought to bear on a fixed distant target. It is again brought on the target when the stand of drill pipe has been lowered. The angle through which the sight must be rotated is a measure of the rotation of the drill pipe.

It is claimed that the use of the hemispheres results in a more accurate record of deviations in spiral holes. It is also claimed that this instrument may be used to indicate the rotations of the drill pipe, at the location of the instrument, as the pipe is lowered into the well.

Devices Making Use of the Magnetic Compass.

Acid Bottle and Maas Compass

The acid bottle is used in a brass bailer in a manner similar to that previously described. However, in addition to the acid bottle a compass needle, moving in a gelatin or tallow bath, is used. After a limited time the tallow or gelatin hardens and holds the compass in the position it assumed when the acid etching was made. The compass case is held in a definite position with respect to the acid bottle and thus enables the direction of inclination of the hole to be determined. The line etched by the acid in the bottle indicates the angle of inclination of the hole.

Ahlburg Instrument

The Ahlburg instrument is owned by the Oil Well Recording Company, and is operated exclusively by Whealton-Townsend Company. It is similar to the one described later as the McCoy instrument. The Ahlburg instrument is being changed at the present time so that the photographs will show the temperature in addition to the positions of the compass and level bubble.

Allan Oliver Instrument

The Allan Oliver instrument operates on the plumb bob and magnetic compass principles. Only one set of readings can be taken with each run of the device. However, the instrument is usually run on a sand line and little time is required to obtain the readings. The instrument is placed in a brass case at the bottom of a 30-foot brass bailer. If desired, the instrument and brass pipe can be run on the bottom of drill pipe. These instruments are rented to oil companies by the month and may be used as often as desired.

The inclination of the hole is obtained by the use of a plumb bob, hanging from a universal joint, and a circular chart. At the predetermined time, which has been set on a clock in the instrument, the chart is raised to a point where it is pierced by the point of the plumb bob. Circles representing 1-degree inclinations are drawn about the center of the chart. The position of the perforation indicates the amount of inclination. The direction of inclination is obtained by use of a horizontally swinging compass. At the predetermined time, the compass is automatically clamped in its position and remains so until released above ground. The clock makes an electrical contact at the predetermined time, which causes an electric motor, driven by dry cell batteries in the instrument, to operate the mechanisms which move the chart up to the plumb bob and clamp the compass in its position. The direction of inclination is in a line through the perforation to the center of the chart. The bearing of this line is obtained by reference to the compass clamped in its magnetic north position.

Argabrite Instrument

The Argabrite instrument operates on the plumb bob and magnetic compass principles. It differs from others of this class in that the readings are transmitted electrically to the surface where they can be read as taken. This permits the instrument, which is run in the hole on a line, to be used for check reading at any desired depth.

The instrument, operating in a universal pendulum, is completely immersed in oil. The universal pendulum consists of a cylinder, weighted down at one side of the bottom, and provided with central bearings at each end which permit unhampered movement about them. The electrical connections with this pendulum are made by brush and ring contacts which are especially designed to eliminate friction.

The compass, moving in a horizontal plane at all times, is provided with a ring about its outer edge. This ring is wrapped with nichrome resistance wire. A light spring holds the compass above this resistance ring. When an electric contact is made above ground, a solenoid, consisting of a hollow cylinder wrapped with copper wire, sets up a strong magnetic field which draws down a weight attached to the compass and thus causes the compass to make an electrical contact with the resistance wire. A current is then passed through the compass and resistance wire. The resistance in this latter circuit is balanced by use of a galvanometer, in a Wheatstone bridge, against a standard resistance coil which is graduated in degrees and minutes to correspond to the compass direction, that is, in proportion to the amount of resistance thrown into the circuit by the compass needle contact.

A semicircular section of a disc, with nichrome wire wrapped around a ring placed on its circular edge, is hung, from the mid-point of its diameter, in a vertical plane in line with the weighted section and axis of the universal pendulum. Its design causes it to move in a vertical plane lying in the direction of drift of the hole at the point where the reading is taken. The center point of the semicircle hangs directly down, as does a plumb bob. When a reading is to be taken, a current is passed through a second solenoid which causes a pointer to make contact with the resistance wire. Another current is then passed through this pointer and the resistance wire. The amount of resistance thrown into the circuit is a measure of the inclination of the hole. This resistance is balanced in a Wheatstone bridge against a known resistance, and the angle of inclination is read directly.

Mr. Argabrite's instrument is equipped with a pyrometer connection which enables the temperature to be taken when the other readings are made. Knowing the temperature at given depths, corrections can be made for the changing resistance of the lines conducting the current to the resistance coils. These corrections are not large as the wire leads have a resistance of only 42 to 43 ohms, while the compass and vertical circle coils have resistance of 11,000 ohms and 4000 ohms, respectively.

Two 12-volt storage batteries are used for operating the solenoids, and dry cells of 3-volt intensity furnish the current for determining the inclination and direction of the hole. A movement from one wrap of nichrome wire to the next one is clearly indicated.

The instrument has an over-all diameter of 3 inches. Its brass container is filled with lead at each end to give it additional weight. It is run on a cable, composed of four electrical conductors, in open hole, and in casing, using a special reel mounted on a truck.

Dale and Nielson Instrument

The Dale and Nielson instrument operates on the plumb bob and magnetic compass principles. A plumb bob, with a lever arm above, causes two styluses to draw lines on two moving strips of paper as the drill pipe is lowered into the hole. A steel needle, on one end of which two bristles are fixed, is held in position by the magnetic field set up by a heavy compass needle below. The former moves in the same direction as the compass needle, and at fixed time intervals scratches the smoked inner surface of a horizontally corrugated paper cylinder. The heavy compass needle moves in a horizontal plane at all times while the other needle moves in a plane at a right angle to the axis of the instrument. The positions of the stylus lines on the two rolls of paper indicate the amount of inclination of the hole from vertical and the direction with respect to the centers of the brass tables over which the paper strips move. The stylus marks indicate two sides of a right triangle and the third side is calculated. The corrugated cardboard cylinder is definitely located with respect to the brass tables. When the inclination and direction with respect to the tables has been calculated, the angle between this direction and magnetic north is then determined. The angle obtained can then be corrected to read in deviation from true north.

The instrument is operated by clock works which are set in motion by a jerk on the drill pipe. It operates for one minute and twenty seconds after each jerk. The apparatus fits in a high chrome steel nonmagnetic case which is screwed on to the bottom of the drill collar. Before lowering each stand of drill pipe, the pipe is given the jerk which sets the mechanism in motion. When the drill pipe is in the slips again, time is allowed automatically for the compass needles to come to rest, after which a raised section of the corrugated cardboard cylinder is moved past the needle, thus making the two bristle marks. However, these marks are only made every two stands.

The instrument shows the number of rotations made by the drill pipe as it is run in the hole. A specially designed thermometer records the maximum temperature obtained. It normally requires one and a half minutes per stand to make a survey by this method.

Mr. Dale states that sometimes this instrument may be used satisfactorily inside of one string of casing, but as a precautionary measure, when surveying inside of casing, the drill pipe is now oriented through the cased part of the hole. He states that the casing ordinarily has no attractive forces on the compass itself, but merely serves to shield the compass from the natural action of the magnetic forces of the earth. He states that in one case his instrument showed the drill pipe had made three revolutions below ground while only a little more than two were noted at the surface. The drill pipe is oriented into the hole by using an instrument somewhat similar to a transit on top of the drill pipe. Before each stand is lowered into the

hole the sight is pointed at a distant object. At the derrick floor, the sight is again pointed on the same object and the angle through which the sight has turned is measured. This angle is a measure of the rotation of the drill pipe at the top of the hole. When used in open hole a survey can be started at any desired depth by lowering the drill pipe to that point and rotating it a number of times before proceeding with the survey. The stylus marks made on the paper charts clearly indicate the time when the pipe was rotated.

Macready Orientation Core Drill

The Macready orientation core drill was devised primarily for use in orienting cores in wildcat drilling. It operates on the magnetic compass and plumb bob principles, although no actual plumb bob is used. The compass needle, turning on a jewel bearing, has a brass framework suspended below it and around the vertical pin which supports the compass needle. The framework supports a brass pointing vane about ½ inch wide and pointed at the end below the north point of the compass. This vane moves with the compass. At the center of the vane, inside the framework, is a hole about ¼ inch in diameter. When the instrument is vertical, the center of this hole and the pin supporting the compass needle coincide. When the instrument is inclined, the center of the hole moves away from the pin supporting the compass a distance proportioned to the inclination of the hole and in a direction directly opposite to the direction of inclination of the hole. The position of the vane at predetermined time intervals is recorded by the use of a roll of photographic exposure paper moving beneath the vane. An electric light operated by dry cells and turned on by clock works furnishes the necessary illumination.

The old type of instrument made just one exposure and at a time set on a clock in the instrument before lowering it into the hole. Sufficient time was allowed for running the drill pipe to bottom and taking a core. Since the time for taking a core was rather indefinite, this system was not completely satisfactory. The spline swivel was next developed which made it possible to take the single picture at any time desired.

A mark is shown in the photographs which is definitely located with respect to a point on the bottom of the inner core barrel which thus permits orienting the cores. The outer core barrel is similar to others commonly used, but the inner core barrel has a shoe cut with vertical lands and grooves which are provided with chisel edges at the bottom. The core moves up through this shoe and is cut with the land and groove markings. The trimmings are carried away by the circulating fluid. Mr. Macready has taken cores in shale 15 feet long without a break. After the cores are removed, they are oriented with respect to the compass and inclination of the hole. Then the dip and direction of dip of the bedding planes in the cores are readily determined.

The new type of instrument taking a number of photographs may be used without a core barrel for making a well survey.

The instrument is provided with a brass case which fits in the center of a 12-foot section of heavy bronze drill pipe to which the outer core barrel is attached.

McCoy Instrument

The McCoy instrument consists essentially of a compass, and level bubble moving in a glass container shaped as a section of a sphere, with lines etched concentrically about the position of the bubble when the instrument is vertical. The rings are drawn at distances equivalent to each degree or each two degrees of dip. An electric light is placed below both the compass and level bubble container. A camera takes a photograph every five minutes of the position of the bubble with respect to the compass. The angular distance between the compass north point and the bubble gives the magnetic bearing of the inclination and the concentric line at which the bubble is located shows the angle of inclination of the hole with respect to vertical.

The mechanical construction is as follows: The apparatus is held in a brass frame about 5 inches in diameter and 56 inches in length. The two lower sections contain dry cell batteries. Above the batteries is a cylindrical aluminum casting. A light bulb is placed in the lower part of the casting and is operated by the dry cell batteries. Above the light bulb, and also in the aluminum cylinder, is a compass held in a frame which keeps the compass level. The compass needle has an especially large head and tail. The compass box is translucent and thus the needle shows up very clearly when the light is on. Just above the compass, but in the cylinder, is the leveling device. A small box camera is attached to the brass frame directly above the compass and leveling device. Just above the camera is a mechanism which turns the film through the camera. This mechanism is driven by a dry cell operated electric motor. Above the motor is a clock which makes electrical contacts every five minutes, and sets the mechanism in action to take the photograph and turn the film. The instrument can make 375 exposures before having to be withdrawn from the hole.

This device is placed in a brass case which usually is attached to the bottom of the drill pipe, though it may be run in a bailer. A special section of drill pipe just above the brass case is equipped with spacers to center the instrument in the hole.

Mr. McCoy claims that when the instrument passes any sidetracked pipe or tools, the compass is not affected when the junk is over two feet distant from the compass, and when it is within this distance, the compass fluctuates rapidly and no picture is obtained. He does not believe the compass needle is reliable when used inside of casing, and in that case the survey is made by the orienting method.

Rieber Instrument

The Rieber instrument was designed primarily for use in forestalling crooked holes rather than in surveying them. However, it can be used as well as other compass instruments for making surveys. Drilling can be carried on as long as desired after taking the readings. This device is also used for orienting cores.

The instrument operates on the magnetic compass and plumb bob principles. The records of inclination and direction are made by punch marks on aluminum discs of about the same diameter and thickness as a fifty-cent piece. Forty discs are provided. They are num-

bered consecutively and are piled in a vertical cylindrical container from which they are automatically fed to the marking devices. After the records are made, the discs are automatically fed into another cylindrical receptacle. The power to operate the instrument is furnished by clock works, which are set in motion by rapidly rotating the drill pipe for about fifteen seconds and then stopping it. This motion sets a pot of mercury in the bottom of the instrument in rotation. Four vertical vanes are placed in the mercury and when the rotation of the drill pipe ceases, the mercury continues to rotate, turning the vanes, which starts the clock works. The records are automatically made fifty seconds after stopping the drill pipe. During this time the compass and plumb bob come to rest and a new stand of drill pipe is made up. The movement of a cam permits the plumb bob with a hard needle point to drop and punch the disc. The compass needle is constructed of special highly magnetic cobalt steel. Attached to the needle is a "T"-shaped frame with the top lying above and parallel to the compass needle. It is provided with a sharp point extended upward from one end of the top of the "T" over the north end of the compass. The frame is automatically raised by a cam which causes the point to make a mark in the under side of the disc, indicating magnetic north. At the same time another mark is punched, nearer the edge of the disc, which indicates the zero point of the instrument. This zero point is directly in line with a lug in the core barrel, when used, which automatically marks the cores, thus permitting them to be oriented. The distance of the plumb bob punch from the center of the disc indicates the angle of inclination, and its position with respect to the compass punch mark indicates the direction of inclination. A special instrument is provided to aid in reading the discs. The compass, moving in a plane at right angle to the axis of the instrument, will only function with less than 38 degrees inclination. The plumb bob will record up to 20 degrees inclination with the regular discs. Larger discs will permit the recordings of angles up to 45 degrees.

The instrument is immersed in oil in a brass case equipped with a pressure relief valve. The case fits in a special joint of nonmagnetic chrome nickle steel drill pipe. Circulation is obtained around the instrument. A 7-foot section of this nonmagnetic drill pipe is placed in the drill string both below and above the device. Four-inch drill pipe is the smallest in which one of these instruments can be used, although a smaller instrument will be available later.

It is claimed that the drill pipe, with the nonmagnetic sections, has no influence on the compass. The use of any magnetic compass inside of casing is not recommended, although it is further claimed that one string of casing may not cause any great error. It is also claimed that casing or drill pipe in another hole will not influence the compass unless it is within a distance of 10 feet. Another hole passing near the one surveyed might throw some readings off, but these discrepancies would be clearly indicated.

The instrument is rented, by the month, to operators, who use it themselves and calculate their own results. The owner recommended that the instrument be used for every 200 to 300 feet of hole drilled.

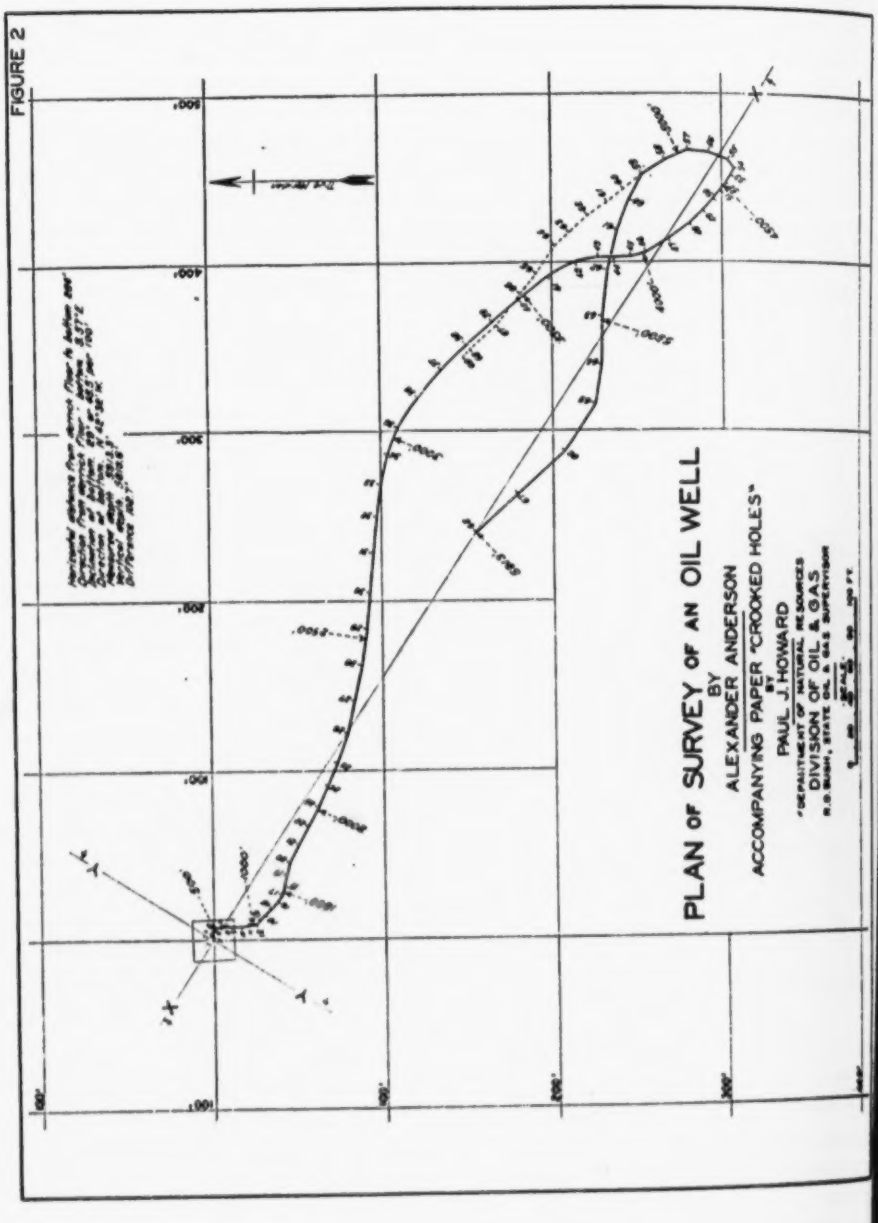

PLAN OF SURVEY OF AN OIL WELL
BY
ALEXANDER ANDERSON
ACCOMPANYING PAPER "CROOKED HOLES"
BY
PAUL J. HOWARD
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL & GAS

FIGURE 2

PAUL J. HOWARD
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL & GAS
R.D. BUSH, STATE OIL & GAS SUPERVISOR

FIGURE 3.

SURVEY OF AN OIL WELL

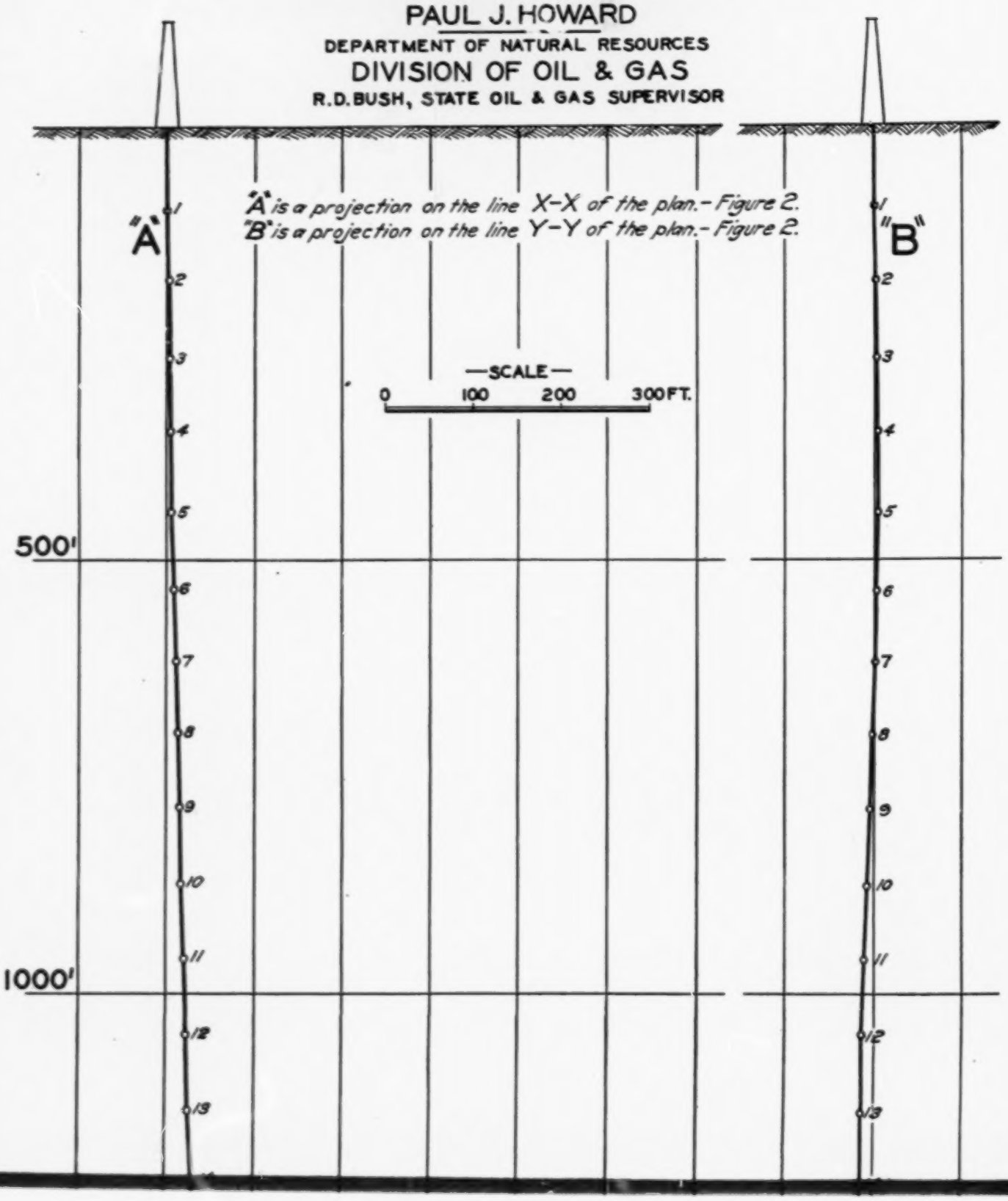
— BY —

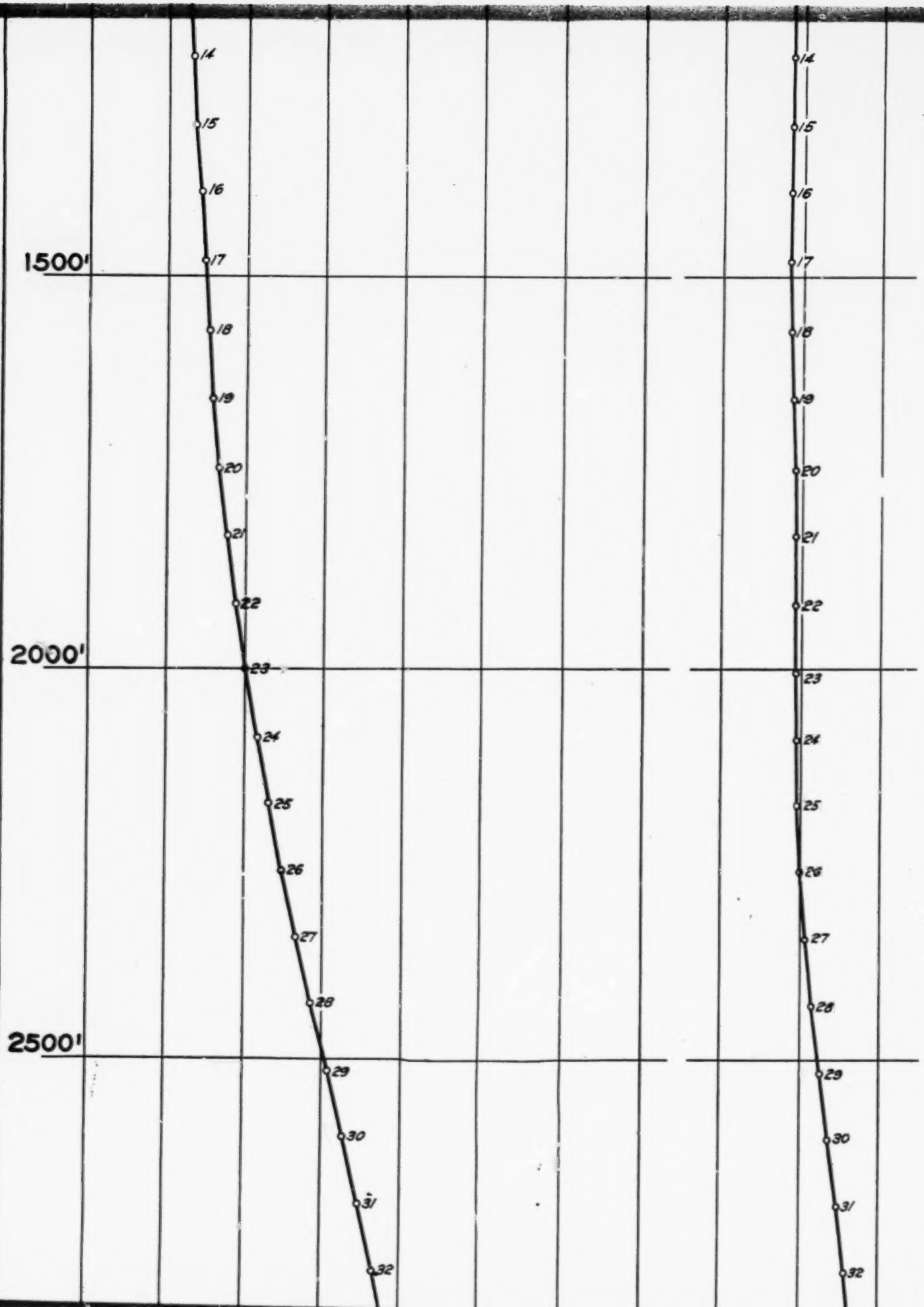
ALEXANDER ANDERSON

ACCOMPANYING PAPER "CROOKED HOLES"

— BY —

PAUL J. HOWARD
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL & GAS
R.D. BUSH, STATE OIL & GAS SUPERVISOR

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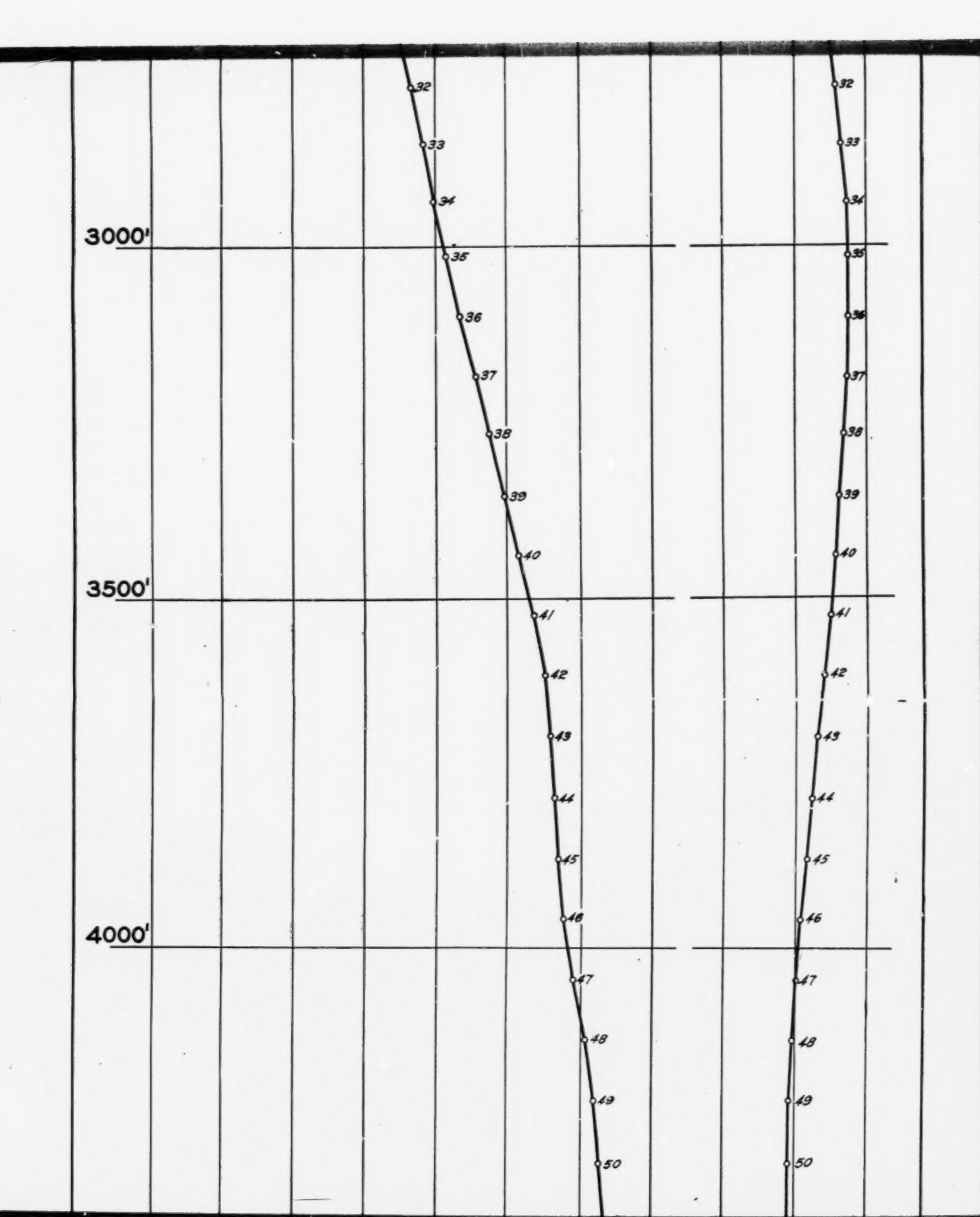
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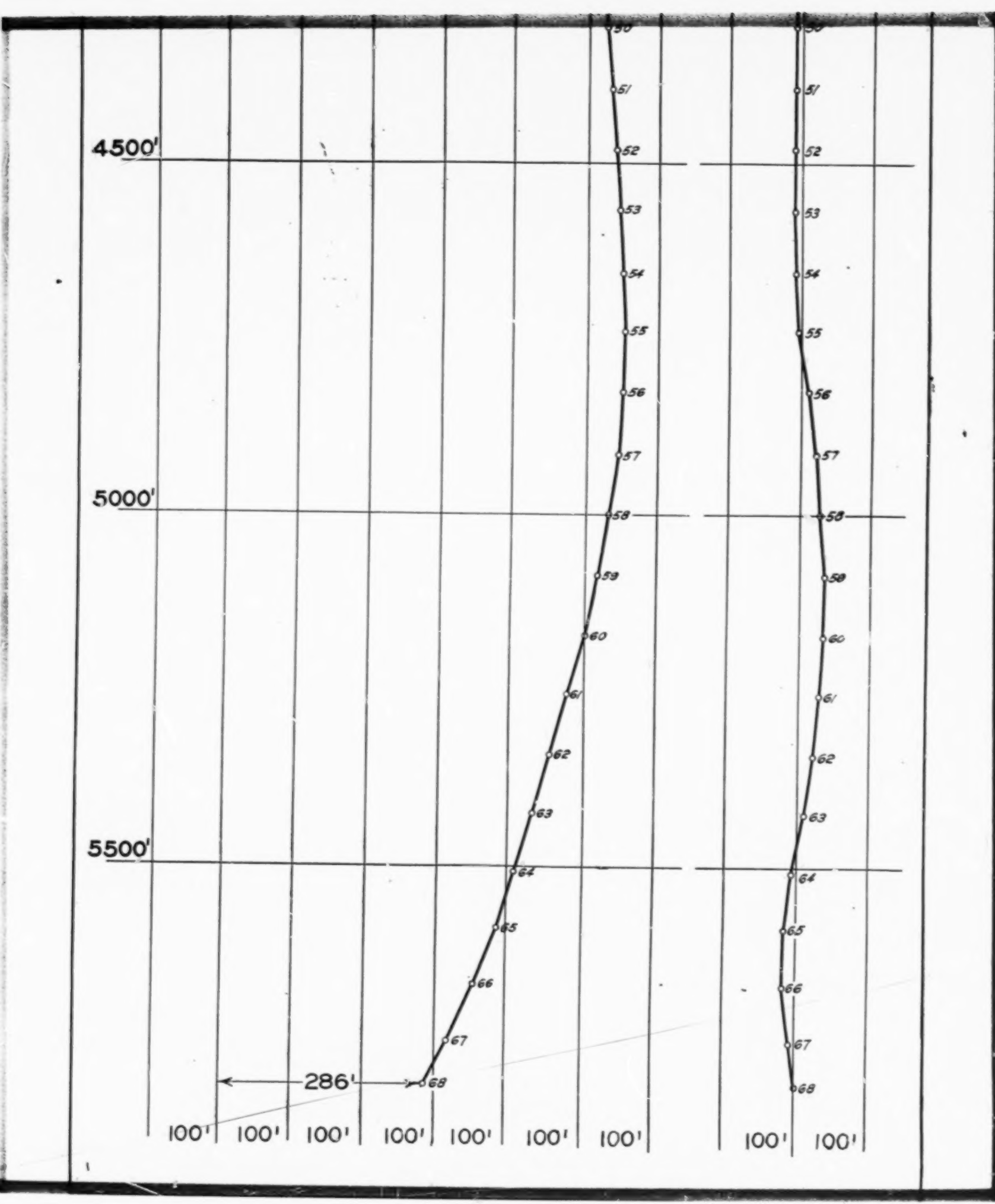
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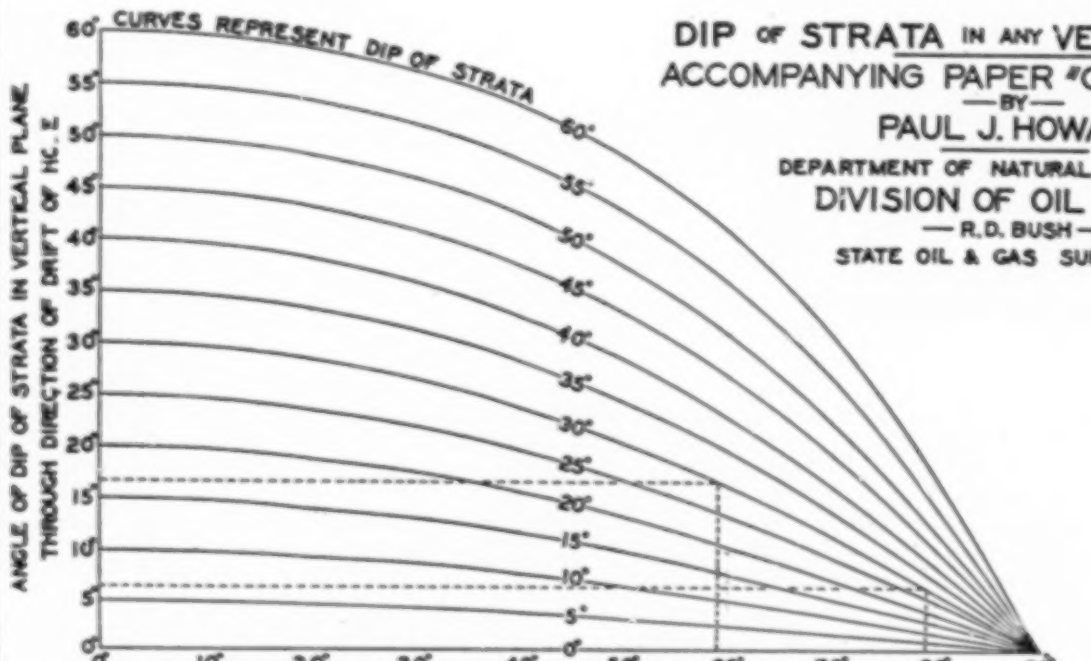
TABLE 3.

SURVEY DATA OF UNDERGROUND COURSE OF ROTARY HOLE

By Alexander Anderson

A	B	C	D	E	F	G	H	
...ding number	Measured depth, feet	Actual vertical depth, feet	Direction of inclination true bearing	Inclination of hole from vertical in degrees	Deviation in feet, per 100	Lengths of stands pipe, feet	Deviation in feet per stand	Total deviation
1	93.08	93.06	.....	0° 20′	0.58	93.08	0.54	
2	178.75	178.75	S. 84° 55′ E.	0° 30′	0.87	85.67	0.75	
3	266.42	266.41	N. 41° 07′ E.	0° 45′	1.31	87.67	1.15	
4	351.25	351.23	N. 71° 46′ E.	0° 45′	1.31	84.83	1.11	
5	443.00	442.94	S. 71° 57′ E.	1° 40′	2.91	91.75	2.67	
6	531.75	531.68	S. 46° 04′ E.	1° 00′	1.75	88.75	1.55	
7	615.50	515.37	S. 12° 03′ E.	2° 15′	3.93	83.75	3.29	
8	700.33	700.12	S. 0° 30′ W.	2° 30′	4.36	84.83	3.70	
9	783.91	783.62	S. 3° 00′ W.	2° 30′	4.36	83.58	3.65	
10	872.83	872.43	S. 0° 44′ E.	2° 50′	4.94	88.92	4.40	23
11	959.83	959.32	S. 7° 11′ E.	2° 50′	4.94	87.00	4.30	
12	1,046.66	1,046.05	S. 9° 04′ E.	2° 45′	4.80	86.83	4.17	
13	1,134.58	1,133.93	S. 45° 53′ E.	1° 50′	3.20	87.92	2.81	
14	1,217.58	1,216.82	S. 50° 36′ E.	3° 00′	5.23	83.00	4.34	
15	1,304.16	1,303.25	S. 40° 57′ E.	3° 20′	5.81	86.58	5.02	
16	1,392.08	1,390.98	S. 48° 56′ E.	3° 45′	6.54	87.92	5.75	
17	1,479.66	1,478.44	S. 53° 18′ E.	3° 00′	5.23	87.58	4.58	
18	1,567.49	1,566.09	S. 75° 10′ E.	3° 40′	6.40	87.83	5.62	
19	1,655.59	1,654.32	S. 77° 44′ E.	4° 30′	7.85	88.50	6.94	
20	1,744.16	1,742.15	S. 75° 57′ E.	5° 00′	8.72	88.17	7.68	74
21	1,832.08	1,829.37	S. 63° 46′ E.	7° 15′	12.62	87.92	11.10	
22	1,919.41	1,915.85	S. 60° 49′ E.	8° 00′	13.92	87.33	12.15	
23	2,007.24	2,002.72	S. 63° 01′ E.	8° 30′	14.78	87.83	12.98	
24	2,095.16	2,089.56	S. 66° 42′ E.	9° 00′	15.64	87.92	13.75	
25	2,179.83	2,172.94	S. 66° 41′ E.	10° 00′	17.37	84.67	14.70	
26	2,268.00	2,259.18	S. 71° 10′ E.	12° 00′	20.79	88.17	18.33	
27	2,356.08	2,345.00	S. 78° 33′ E.	13° 00′	22.50	88.08	19.81	
28	2,444.08	2,430.39	S. 76° 59′ E.	14° 00′	24.19	88.00	21.29	
29	2,531.33	2,514.92	S. 82° 28′ E.	14° 20′	24.76	87.25	21.60	
30	2,619.83	2,600.66	S. 84° 28′ E.	14° 20′	24.76	88.50	21.91	242
31	2,707.66	2,685.36	S. 84° 27′ E.	15° 20′	26.44	87.83	23.22	
32	2,795.66	2,770.75	S. 84° 45′ E.	14° 00′	24.19	88.00	21.29	
33	2,878.83	2,851.79	S. 83° 45′ E.	13° 00′	22.50	83.17	18.71	
34	2,966.83	2,937.87	S. 76° 15′ E.	12° 00′	20.79	88.00	18.30	
35	3,045.00	3,014.33	S. 69° 59′ E.	12° 00′	20.79	78.17	16.25	
36	3,132.92	3,099.76	S. 56° 20′ E.	13° 40′	23.63	87.92	20.77	
37	3,220.92	3,185.15	S. 51° 39′ E.	14° 00′	24.19	88.00	21.29	
38	3,305.84	3,267.43	S. 46° 13′ E.	14° 20′	24.76	84.92	21.02	
39	3,393.84	3,353.06	S. 40° 12′ E.	13° 20′	23.06	88.00	20.29	
40	3,482.34	3,439.05	S. 42° 24′ E.	13° 40′	23.63	88.50	20.91	444
41	3,570.34	3,524.44	S. 38° 24′ E.	14° 00′	24.19	88.00	21.29	
42	3,657.42	3,609.62	S. 27° 04′ E.	12° 00′	20.79	87.08	18.10	
43	3,745.25	3,696.37	S. 12° 31′ E.	9° 00′	15.64	87.83	13.74	
44	3,832.25	3,782.85	S. 2° 33′ W.	6° 15′	10.89	87.00	9.47	
45	3,920.17	3 870.23	S. 2° 25′ E.	6° 20′	11.03	87.92	9.70	
46	4,008.09	3,957.61	S. 14° 42′ E.	6° 20′	11.03	87.92	9.70	
47	4,096.01	4,044.24	S. 33° 03′ E.	9° 50′	17.08	87.92	15.01	
48	4,182.93	4,129.75	S. 36° 27′ E.	10° 20′	17.94	86.92	15.59	
49	4,271.01	4,217.13	S. 43° 18′ E.	7° 15′	12.62	88.08	11.12	
50	4,358.84	4,304.48	S. 48° 34′ E.	6° 00′	10.45	87.83	9.18	577
51	4,446.76	4,392.19	S. 52° 31′ E.	4° 00′	6.98	87.92	6.13	
52	4,534.59	4,479.83	S. 46° 26′ E.	3° 45′	6.54	87.83	5.74	
53	4,621.59	4,566.64	S. 59° 43′ E.	3° 45′	6.54	87.00	5.69	
54	4,708.67	4,653.60	S. 63° 03′ E.	3° 00′	5.23	87.08	4.56	
55	4,793.42	4,738.14	N. 51° 33′ E.	4° 00′	6.98	84.75	5.91	
56	4,881.67	4,825.46	N. 21° 52′ E.	8° 20′	14.49	88.25	12.79	
57	4,969.42	4,912.36	N. 6° 00′ E.	8° 00′	13.92	87.75	12.21	
58	5,057.34	4,999.12	N. 24° 08′ W.	9° 20′	16.22	87.92	14.26	
59	5,145.34	5,085.78	N. 32° 13′ W.	10° 00′	17.37	88.00	15.28	
60	5,233.26	5,172.08	N. 61° 25′ W.	11° 00′	19.08	87.92	16.78	676
61	5,321.09	5,257.83	N. 69° 29′ W.	12° 30′	21.64	87.83	19.01	
62	5,408.76	5,342.10	N. 76° 34′ W.	16° 00′	27.56	87.67	24.17	
63	5,496.76	5,425.79	N. 83° 28′ W.	18° 00′	30.90	88.00	27.19	
64	5,585.01	5,509.23	N. 88° 32′ W.	19° 00′	32.56	88.25	28.73	
65	5,668 59	5,589.37	N. 81° 15′ W.	16° 30′	28.40	83.58	23.74	
66	5,756.59	5,670.82	N. 57° 28′ W.	22° 15′	37.87	88.00	33.32	
67	5,844.59	5,750.58	N. 43° 18′ W.	25° 00′	42.26	88.00	37.19	
68	5,913.26	5,810.64	N. 42° 32′ W.	29° 00′	48.48	68.67	33.29	903

FIGURE 4


DIP OF STRATA IN ANY VERTICAL PLANE
ACCOMPANYING PAPER "CROOKED HOLES"
— BY —
PAUL J. HOWARD
DEPARTMENT OF NATURAL RESOURCES
DIVISION OF OIL & GAS
— R.D. BUSH —
STATE OIL & GAS SUPERVISOR
CURVES REPRESENT DIP OF STRATA
ANGLE OF DIP OF STRATA IN VERTICAL PLANE THROUGH DIRECTION OF DRIFT OF HOLE
60° 55° 50° 45° 40° 35° 30° 25° 20° 15° 10° 5° 0°
0° 10° 20° 30° 40° 50° 60° 70° 80° 90°
ANGLE BETWEEN DIRECTION OF DRIFT OF HOLE AND DIRECTION OF DIP OF STRATA
90° 80° 70° 60° 50° 40° 30° 20° 10° 0°
ANGLE BETWEEN DIRECTION OF DRIFT OF HOLE AND STRIKE OF STRATA

Actual Survey of a Well at Long Beach.

Figs. 2 and 3 and Table 3 show the results of a survey made by Alexander Anderson of a well in the south side of the Long Beach field. In the vicinity of this well, the strata dip at an angle of about 30 degrees from the horizontal and the direction of the dip is about south 13 degrees west. The numbers along the curve in the plan view designate the number of stands of drill pipe in the hole when the readings for those particular points were taken. The broken line shows the result of a survey of the hole redrilled from the fifty-ninth stand. The original hole drifted about 550 feet horizontally in a southeasterly direction from its starting point and then turned back until the distance was only 286 feet. The corrected vertical depth was 5811 feet while the drill pipe measured 5913 feet. The hole was redrilled, using a whipstock, from about 5100 feet because of the mechanical condition of the well. The new hole drifted in a northwesterly direction until at the time of the second survey it was 368 feet from the derrick in the direction south 66 degrees east. The corrected vertical depth at this point was 5873 feet while the drill pipe measurement was 5946 feet. At the bottom of the well the hole was going north 46 degrees west with an inclination from vertical of 15 degrees 45 minutes.

Computation Charts.

Computation charts (Figs. 4 and 5) are submitted in the hope that they may increase the usefulness of oil well surveys. The charts provide a means for solving three dimensional problems graphically without a knowledge of descriptive geometry. If the rules herein provided are followed, the problems can be readily solved.

Suppose (1) the dip and direction of dip of the strata are known for a certain section of a field, (2) the correct depth to a certain shale body is known, (3) a survey of a well has been made and the direction and amount of drift have been determined, and (4) the corrected depth has been obtained. The problems will be to determine the vertical distance of the shale body from the bottom of the hole and the distance the hole will have to be drilled, in the direction it takes at the bottom, to encounter the shale body or to determine how much too far it has been drilled.

Detailed explanation of steps taken in solving problems:

1. To determine the dip and direction of dip of the strata: If the dip of the strata is not known, procure a map showing the contours of the top of an oil zone or shale body in the vicinity and locate the position of the well on the map. Using a scale equal to that of the map, measure the shortest distance between two or more contour lines in the vicinity of the well. Divide the difference in elevation of the contour lines by the map distance between them. This gives the tangent of the angle of dip of the strata. Turn to a table giving the natural functions of angles and find the angle whose tangent most nearly equals that obtained by the division. If preferred, a right triangle can be constructed using the map distance as the base and the difference in elevation of the contour lines as the altitude. A protractor may be used to measure the angle opposite the altitude. This is the angle of dip of the strata. The direction of dip is the direction, down dip, at a

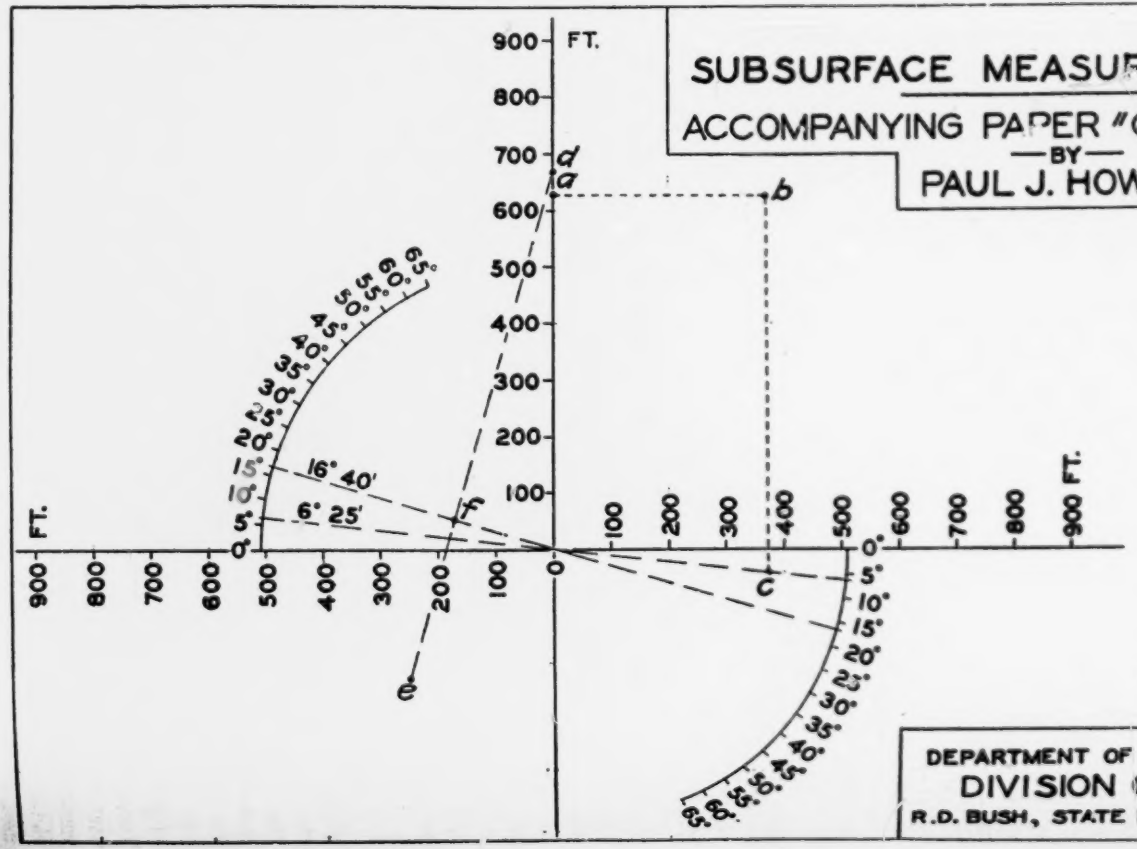
FIGURE 5

SUBSURFACE MEASUREMENT CHART

ACCOMPANYING PAPER "CROOKED HOLES"

—BY—

PAUL J. HOWARD



DEPARTMENT OF NATURAL RESOURCES

DIVISION OF OIL & GAS

R.D. BUSH, STATE OIL & GAS SUPERVISOR

right angle to the contour lines at the well position. A protractor may be used to give the angle with respect to a north or south line. The direction of the strike of the strata at the chosen point is the bearing of the contour lines with respect to north or south.

2. To determine the correct depth to a particular shale body or oil measure: Maps are usually available showing the contour lines of the tops of various producing horizons. However, this is not always true in the case of deep sands. In any event, by experience and by means of surveys, it may become known that a deep sand exists at a certain distance below the top of a sand which has been contoured. The depth to the last contoured sand is obtained by adding the elevation of the derrick floor above sea level to the proper interpolated contour passing through the well location. To this summation is added the distance between the contours and the top of the deep sand desired, which is the bottom of the overlying shale or shell body.

3. The direction and horizontal distance of the bottom of the hole from its mouth is given in the survey report or it can easily be determined from the data given.

4. The corrected depth is also given in the survey report.

It next becomes necessary to know the vertical angle made by the desired stratum intersecting a vertical plane drawn through the mouth and bottom of the hole. This is necessary in order to plot the desired stratum, the horizontal drift and the corrected depth, all in one plane surface so that the vertical distance from the bottom of the hole to the stratum may be measured directly.

This angle of dip of the strata in the direction of drift of the hole may be obtained by using Fig. 4 if the dip of the strata is known. If desired, it may be obtained in a manner similar to that described for obtaining the dip of the strata at a right angle to the contour lines, except that the scale is laid in the direction of drift of the hole instead of at a right angle to the contour lines.

Use of Figure 4.

Determine the angle between the direction of drift of the hole and the direction of maximum dip of the strata. Using the figures below the chart running from 0 degrees to 90 degrees (left to right), locate the reading corresponding to the angle just determined. Go to a point directly above this on the curve indicating the dip of the strata in the vicinity of the well. Next read the angle on the vertical scale corresponding to this point. This, then, is the angle made by the strata cutting a vertical plane lying in the line of drift of the hole. If desired, the angle between the line of strike of the strata, that is, parallel to the contour lines, and the direction of drift may be used. If this is done, the lower horizontal scale reading from 90 degrees to 0 degrees (left to right) is used.

Use of Figure 5.

Lay off a line at the angle of the shale body as determined from Fig. 4 through the zero point of Fig. 5. Using the zero point as the point directly below the derrick where the shale body or top of the oil measures should be encountered, lay off, in a vertical direction, the differ-

ence between the corrected depth of the hole, taken from the survey, and the expected depth to the oil sands or shale body. Then from this position lay off another point in a horizontal direction, either up dip or down dip as the case may be, at a distance equal to that between the bottom of the hole and a vertical line through the derrick location. The vertical distance from this point to the line representing the reference stratum is then measured. It represents the actual vertical distance from the bottom of the hole to the shale body. Next lay off this latter interval vertically above the zero point. Next must be known the dip of the strata in a vertical plane through the lower section of the hole or in a line representing the probable course of the hole when continued. This angle is obtained by the use of Fig. 4 as before, except that in this case the horizontal angle between the direction of maximum dip of the strata and the probable course of the hole is measured or calculated. Now lay off through the zero point the angle of dip of the strata in the vertical plane through the probable direction of the hole. Next the angle of inclination of the lower portion of the hole, or its estimated continuation, is laid off as an angle about the point, representing the bottom of the surveyed hole, which was moved to the zero line. This angle is laid off to the right or to the left, depending upon whether the hole drifts down or up structure. The length of this line to the shale body, last plotted, is the probable distance which the hole will have to be drilled to reach that shale body, or oil sand, as the case may be.

Similar charts may be constructed using a scale suitable to the nature of the problem.

When using these charts it must be assumed that:

1. The dip of the strata lying above the oil sands is known.
2. The depth to the required stratum below the well location is known.
3. The survey data are correct.
4. The estimated direction and inclination of the proposed extension of the hole will hold true.

The results obtained by the use of these charts will be comparable to the degree of accuracy of the assumptions.

Example of Use of Computation Charts.

The results of the survey shown in this article may be used to illustrate the use of the computation charts.

The redrilled hole was surveyed to a measured depth of 5946 feet. The survey shows the following:

1. Corrected vertical depth 5873 feet.
2. Bottom of hole 368 feet distant, horizontally, from the derrick in the direction south 66 degrees east.
3. The hole at the bottom was going north 46 degrees west at an inclination of 15 degrees 45 minutes from vertical.

Corrected correlation indicates that a 20-foot shale body should be encountered at a depth of 6500 feet directly below the derrick floor. The strata in the vicinity of this well will have a dip of 30 degrees in a direction south 13 degrees west.

Required: To find the distance the well must be drilled to reach the desired shale body.

Solution:

1. Find the dip of the shale body in the vertical plane through the direction of drift (south 66 degrees east) of the hole as shown by the survey.

The horizontal angle between the direction of drift of the hole (south 66 degrees east) and the direction of dip of the strata (south 13 degrees west) is 66 degrees + 13 degrees = 79 degrees. Refer to Fig. 4. Find 79 degrees along the base of the diagram. Go vertically to a point directly above 79 degrees on the curve indicating the dip of the strata (30 degrees in this case). Then move horizontally to the left of the diagram and read the dip of the strata in the direction of drift of the hole. This is 6 degrees 25 minutes. Lay off this angle through the zero point in Fig. 5.

2. Find the dip of the strata in the vertical plane through the lower portion of the hole (that is north 46 degrees west or south 46 degrees east).

The angle between this direction and the direction of the dip of the strata is 46 degrees + 13 degrees = 59 degrees. Then using 59 degrees and referring to Fig. 4 as before, the dip of the strata in the direction the hole is going at the bottom is found to be 16 degrees 40 minutes. Lay this angle off through the zero point in Fig. 5.

Next obtain the difference between the corrected depth of the bottom of the hole at the time of survey (5873 feet) and the vertical depth to the shale body from the derrick floor (6500 feet). This value is 627 feet. Lay this distance off (Oa) in Fig. 5 directly above the zero point. Next lay off horizontally from this point the horizontal drift of the hole (368 feet) (a-b). This is laid off to the right because the hole drifted down structure. The distance (b-c) is the vertical distance from the bottom of the hole to the shale body (667 feet).

As usually the hole will not be vertical at the bottom, the distance it will have to be drilled must next be obtained. Lay off the distance O-d equal to c-b. Then lay off the angle e-d-O equal to the inclination of the hole at the bottom (15 degrees 45 minutes). This angle may be laid off in deviation in feet per 100 feet if desired. This angle is laid off to the left because the hole is going up structure at the bottom. The distance d-f is the additional distance the hole will have to be drilled to reach the shale body (636 feet).

This distance added to the measured depth of the surveyed hole equals 6582 feet and represents the measured depth of the hole where the shale body should be encountered.

Conclusion.

It is hoped that this article may serve a useful purpose by presenting information on straight hole drilling practice, in describing various possible complications associated with crooked holes, and in submitting charts which may be helpful in solving crooked hole problems.

This paper indicates the need for correlation of deep lying oil measures, which can only be accomplished by the compilation of data, based on reliable surveys, furnished by numerous operators.

At the present time, most operators are reluctant to release information in regard to the underground positions of their wells, thus making it almost impossible to obtain accurate correlation data, but for their own protection and for the protection of oil and gas sands from damage by water through improper drilling based on erroneous data, this information should be made available in some form.

RUNS TO STILLS AND OUTPUT OF OIL REFINERIES IN THE UNITED STATES APRIL, 1929

(Statistics by U. S. Bureau of Mines)

Input	Crude oil		Unfinished oils, rerun	Natural gasoline	Total input (bbls.)
	Domestic	Foreign			
East Coast	8,354,000	5,424,000	1,269,000	288,000	15,335,000
Appalachian	2,918,000	----------	124,000	35,000	3,077,000
Indiana, Illinois, Kentucky, etc.	8,733,000	----------	586,000	163,000	9,482,000
Oklahoma, Kansas, Missouri	9,539,000	----------	362,000	290,000	10,191,000
Texas	17,033,000	403,000	870,000	776,000	19,082,000
Louisiana and Arkansas	5,702,000	833,000	104,000	565,000	7,204,000
Rocky Mountain	2,181,000	----------	679,000	127,000	2,987,000
California	19,339,000	----------	[1]559,000	[2]1,358,000	21,256,000
United States totals	73,799,000	6,660,000	4,553,000	3,602,000	88,614,000
Daily average, April, 1929	2,460,000	222,000	151,800	120,000	2,953,800
Daily average, March, 1929	2,390,100	213,300	105,900	120,600	3,829,900
Texas Gulf Coast	12,009,000	403,000	500,000	640,000	13,552,000
Louisiana Gulf Coast	3,557,000	833,000	91,000	460,000	4,941,000

OUTPUT AND LOSSES

	Gasoline (bbls.)	Kerosene (bbls.)	Gas and fuel oils (bbls.)	Lubricants (bbls.)	Wax (lbs.)
East Coast	4,505,000	743,000	7,534,000	907,000	24,735,000
Appalachian	1,346,000	297,000	676,000	435,000	9,161,000
Indiana, Illinois, Kentucky, etc.	5,090,000	441,000	2,865,000	336,000	5,987,000
Oklahoma, Kansas, Missouri	4,981,000	910,000	3,206,000	233,000	3,629,000
Texas	7,458,000	785,000	8,094,000	666,000	6,109,000
Louisiana and Arkansas	2,508,000	430,000	3,091,000	101,000	4,231,000
Rocky Mountain	1,436,000	110,000	580,000	52,000	4,124,000
California	7,312,000	718,000	11,487,000	169,000	----------
United States totals	34,636,000	4,434,000	37,533,000	2,899,000	57,976,000
Daily average, April, 1929	1,154,500	147,800	1,251,100	96,600	1,932,500
Daily average, March, 1929	1,111,800	145,600	1,208,300	94,900	1,818,500
Texas Gulf Coast	5,607,000	535,000	5,045,000	630,000	6,002,000
Louisiana Gulf Coast	1,893,000	376,000	1,811,000	84,000	4,231,000

OUTPUT AND LOSSES—Continued

	Coke (tons)	Asphalt (tons)	Other finished products (bbls.)	Unfinished products (bbls.)	Losses (bbls.)
East Coast	13,100	137,100	114,000	32,000	590,000
Appalachian	3,200	1,100	34,000	68,000	166,000
Indiana, Illinois, Kentucky, etc.	31,200	37,400	177,000	67,000	121,000
Oklahoma, Kansas, Missouri	28,900	1,400	51,000	212,000	414,000
Texas	33,500	22,300	8,000	860,000	907,000
Louisiana and Arkansas	11,200	38,000	179,000	442,000	179,000
Rocky Mountain	9,400	1,000	8,000	674,000	46,000
California	200	44,300	192,000	[3]642,000	487,000
United States totals	130,700	282,600	763,000	2,997,000	2,910,000
Daily average April, 1929	4,360	9,420	25,400	99,900	97,000
Daily average, March, 1929	4,170	7,340	23,800	92,700	83,900
Texas Gulf Coast	27,700	22,200	2,000	715,000	746,000
Louisiana Gulf Coast	11,200	32,400	176,000	293,000	62,000

NOTE—Wax, coke and asphalt equivalent to 278.7 pounds per barrel and 5.15 and 5.52 barrels per ton, respectively.

[1] Includes 173,000 barrels net tops produced.

[2] Includes 150,000 barrels run through pipe lines.

STOCKS HELD BY OIL REFINING COMPANIES IN THE UNITED STATES APRIL 30, 1929

(Statistics by U. S. Bureau of Mines)

	Gasoline (bbls.)	Kerosene (bbls.)	Gas and fuel oils (bbls.)	Lubricants (bbls.)
East Coast	7,525,000	1,148,000	5,731,000	2,820,000
Appalachian	1,850,000	262,000	1,029,000	1,018,000
Indiana, Illinois, Kentucky, etc.	7,862,000	628,000	2,386,000	651,000
Oklahoma, Kansas, Missouri	5,622,000	658,000	5,316,000	468,000
Texas	6,933,000	1,317,000	11,685,000	2,187,000
Louisiana and Arkansas	2,575,000	554,000	6,171,000	130,000
Rocky Mountain	2,625,000	200,000	1,086,000	153,000
California	12,023,000	2,730,000	----------	905,000
United States totals	[1]67,015,000	7,497,000	[1]35,404,000	8,341,000
U. S. totals, March 31, 1929	[2]43,205,000	7,855,000	[2]30,195,000	8,853,000
Texas Gulf Coast	5,915,000	1,204,000	8,556,000	2,124,000
Louisiana Gulf Coast	2,318,000	526,000	4,880,000	124,000

STOCKS HELD BY OIL REFINING COMPANIES—Continued

	Wax (lbs.)	Coke (tons)	Asphalt (tons)	Other finished products (bbls.)	Unfinished oils (bbls.)
East Coast	79,915,000	21,800	111,400	69,000	8,471,000
Appalachian	20,060,000	3,200	1,400	64,000	1,405,000
Indiana, Illinois, Kentucky, etc.	14,890,000	39,000	38,000	221,000	3,991,000
Oklahoma, Kansas, Missouri	8,460,000	85,000	2,700	54,000	2,154,000
Texas	8,901,000	158,400	7,000	15,000	10,964,000
Louisiana and Arkansas	16,194,000	55,700	31,700	56,000	2,486,000
Rocky Mountain	22,267,000	81,500	7,400	32,000	1,858,000
California	----------	300	49,200	224,000	[3]8,516,000
United States totals	170,687,000	444,900	248,800	735,000	39,645,000
U. S. totals, March 31, 1929	158,404,000	402,400	250,100	691,000	38,471,000
Texas Gulf Coast	8,637,000	146,800	6,900	8,000	9,704,000
Louisiana Gulf Coast	16,194,000	55,500	27,300	54,000	1,960,000

[1] East of California.
[2] Revised by addition of 1,000,000 barrels to east coast.
[3] Includes 1,695,000 barrels tops in storage.

GASOLINE

Amount of Gasoline Produced Each Month and Stocks on Hand at End of Each Month in California and the United States

(Statistics by U. S. Bureau of Mines)

	California		United States	
	Output, (barrels)	Stocks, (barrels)	Output, (barrels)	Stocks, (barrels)
1928—				
January	5,193,000	13,015,000	27,962,000	37,380,000
February	4,821,000	13,205,000	26,762,000	39,860,000
March	5,209,000	13,602,000	29,311,000	41,089,000
April	4,977,000	13,562,000	29,300,000	41,195,000
May	5,257,000	12,868,000	30,837,000	38,230,000
June	5,659,000	12,615,000	30,793,000	34,862,000
July	5,775,000	11,219,000	32,959,000	30,394,000
August	5,778,000	9,794,000	33,937,000	27,075,000
September	5,549,000	9,339,000	33,670,000	26,378,000
October	5,967,000	8,708,000	34,415,000	26,435,000
November	5,770,000	8,931,000	33,065,000	29,185,000
December	6,721,000	8,921,000	33,934,000	33,066,000
1929—				
January	6,998,000	10,134,000	34,335,000	40,648,000
February	5,975,000	10,186,000	31,264,000	45,704,000
March	7,416,000	11,293,000	34,467,000	*48,205,000
April	7,312,000	12,023,000	34,636,000	47,015,000
May				
June				
July				
August				
September				
October				
November				
December				

* Revised figure.

REPORTS ISSUED BY STATE OIL AND GAS SUPERVISOR DURING MONTH OF JUNE, 1929

The accompanying table shows the number and kind of reports issued by the State Oil and Gas Supervisor to oil operators in each field of the State of California during the month for which operations are herein summarized. Briefs of the Supervisor's findings and recommendations, as set forth in each report, are summarized under oil districts and fields in the pages which follow.

Reports by the Supervisor are of two kinds, namely, those passing upon proposed operations and those passing upon work which has been inspected or tests which have been witnessed by a representative of the Supervisor during progress of the work or after completion.

Reports in reply to notices filed by the operator covering drilling, deepening, redrilling or abandonment operations, and bearing the operator's proposed method of carrying out the work, are called P reports. Each P report has a serial number. For example, the abbreviation "P 1-6183" means report No. 6183 on a proposed operation in District No. 1. Reports giving the results of tests and inspections are called T reports, and are numbered in a similar manner.

The state is divided into five districts, as follows:

District No. 1, including the counties of Los Angeles, Riverside, Orange, San Diego, Imperial and San Bernardino.

District No. 2, the county of Ventura.

District No. 3, including the counties of Santa Barbara, San Luis Obispo, Monterey, Santa Cruz, San Benito, Santa Clara, Contra Costa, San Mateo, Alameda and San Francisco.

District No. 4, including the counties of Tulare, Inyo and Kern.

District No. 5, including the counties of Fresno, Madera, Kings, Mono, Mariposa, Merced and all other counties in California not included in any of said other districts.

Field offices are maintained in District No. 1 at Los Angeles, with branch field offices at Huntington Beach and Long Beach.

In Districts No. 2, No. 3 and No. 5, the field offices are at Santa Paula, Santa Maria and Coalinga, respectively.

In District No. 4 the main field office is at Taft, with a branch field office at Bakersfield.

MONTH OF JUNE, 1929

Field or county[1]	Tests		Proposals					
			New wells				Abandon	
	Routine	Inspection	Drill	Supplementary	Deepen	Redrill	First	Supplementary
Dist. 1—Brea-Olinda	1	1		1				
Coyote Hills		1		1	2			
Domingues	2	2						
Huntington Beach	1	2	2	2		3	3	
Inglewood			1					
Lawndale	5	1		4	1		13	
Long Beach	37	39	8	10	5	9	1	
Newhall			1					
Newport							1	1
Potrero	2	1						
Richfield	1	2	3	1			3	
Rosecrans	4	3			1	1	1	
Santa Fe Springs	76	44	16	41	15	6	1	
Seal Beach	9	7	4	2	3	1		
Torrance						1	1	
Los Angeles County			3	1			2	
Orange County			1					
San Bernardino County			1				1	
San Diego County			1					
Totals	138	103	41	63	27	21	27	1
Dist. 2—Ojai	1			1				
Rincon	1	1		1				
Santa Paula	2	1						
Sespe	1							
Simi			1					
South Mountain	1						1	
Ventura	17	12	6	2		2		
Totals	23	14	7	4		2	1	
Dist. 3—Elwood		1	1	1			1	
Lompoc						1		
Summerland			1			1		
Santa Barbara County			30	1			3	
Totals		1	32	2		2	4	
Dist. 4—Belridge	2	1	2	1				
Buttonwillow Gas			2				1	
Elk Hills		2	1		1	4	1	
Fruitvale	4	1	1	1		2		
Kern River	3	2	4	1				
McKittrick		3						
Midway	6	8	5	6	2	5	2	
Mt. Poso	4		1	1			2	
Round Mountain			1	1				
Sunset	8	6	1	6	1	2		3
Kern County			1	1				
Totals	27	23	19	18	4	13	6	3
Dist. 5—Coalinga	1	1	1			2		
Kettleman Hills	4	4	5	2				
Colusa County			1					
Fresno County			4	1				
Kings County			1					
Mendocino County			1					
Totals	5	5	13	3		2		
Grand totals	193	146	112	90	31	40	38	4

District No. 1

BREA-OLINDA FIELD

T. 3 S., R. 10 W., S. B. B. and M.

Sec. 1—Brea Canon Oil Co. well No. 45. (Report No. P 1-19915.) Supplementary proposal to drill approved provisionally. Conditions: Depth 6115'; 15½" cemented at 2000'; 10" cemented at 4088', perforated 4088'-4400'; 6½" landed at 5501', perforated 4400'-5501', cemented through perforations at 4400'; shot 5515'-20'; plugged with cement 5600'-5290'; tests indicate formations 4400'-5290' contain edgewater and no oil. Proposed to plug solid with cement 5290'-4405' and have division witness for hardness; cut and pull 6½" at 4100'; place cement plug 4100'-4088'; cut and pull 10" at 1950'; produce well 3400'-4088'. Decision: Proposal is approved provided that: (1) Cement plug 5290'-4400' is placed under at least 500 lb. pressure. (2) Division is notified to witness location and hardness of cement plug at 4400'.

Brea Canon Oil Co. well No. 45. (Report No. T 1-17846.) Inspection of cementing operations. Cleaned out to 5290'; plugged with 160 sacks cement in 20' stages 5290'-4350' without pressure; water was run in hole during operations to put pressure on cement plug. Inspector noted bailer could not be spudded below 4345' and brought up sample of set cement. Location and hardness of cement plug at 4345' are approved. Note: Attention is directed to fact that cement plug should have been placed under at least 500 lb. pressure as required in Report No. P 1-19915.

Sec. 2—Brea Canon Oil Co. well No. 46. (Report No. T 1-17889.) Bailing test approved. 15½" casing cemented at 1201'. Hole bailed to 695' for test and stood 12 hr. No fluid entered well.

COYOTE HILLS FIELD

T. 3 S., R. 11 W., S. B. B. and M.

Sec. 13—Standard Oil Co. well No. "Emery" 10. (Report No. P 1-19998.) Proposal to redrill oil string and deepen approved. Conditions: Depth 3512'; redrilled to 3338'; 10¾" landed at 3015'; 8⅝" cemented at 3132'; 6⅝" cemented at 3180', put together with die collar at about 1180'; 4½" landed at 3310', perforated 2957'-3310'. Proposed to clean out to 3338' and plug with cement 3338' to vibration point on 4½"; recover 4½" from below 6⅝" shoe at 3180'; redrill to 3513' and deepen to about 3780'; recomplete with 4½" oil string.

Standard Oil Co. well No. "Emery" 43-A. (Report No. P 1-19954.) Proposal to drill approved. Conditions: Well is 269.8' N. of S. line of section, and 754.8' W. of E. line of section. Proposed to cement 24" at 95'; cement 16" at 3200'-50'; notify division to witness test of water shut-off on 16", also prior to landing or cementing any further casing; maintain mud fluid to surface at all times during drilling operations; fill any side-tracked hole with cement.

Sec. 24—Standard Oil Co. well No. "Emery" 24. (Report No. P 1-19999.) Proposal to redrill oil string and deepen approved. Conditions: Depth 3800'; redrilled to 3459'; 10¾" cemented at 2985'; 8⅝" cemented at 3169'; 6⅝" cemented at 3240'; 4½" landed at 3438', including 316' perforated. Proposed to clean out to 3438' and plug with cement from 3438' to vibration point on 4½" casing; recover 4½" from below 6⅝" shoe at 3240'; redrill to 3800' and deepen to about 4100'; recomplete with 4½" oil string.

Standard Oil Co. well No. "Emery" 44. (Report No. P 1-19940.) Supplementary proposal to drill approved. Conditions: Depth 4100'; 18" cemented at 400'; 11¾" cemented at 3262'; water witch shows water enters at 3445' in well No. "Emery" 45. Proposed to land 9" at 4100', perforate 3525'-4100' and cement through perforations at 3525'.

DOMINGUEZ FIELD

T. 3 S., R. 13 W., S. B. B. and M.

Sec. 34—Shell Oil Co. well No. "Reyes" 39. (Report No. T 1-17792.) Inspection of mudding operations. During ½ hr. circulation test mud fluid was lost from pit at rate of 4 bbl. per hr. Mudding operations are approved. Oral approval given to cement 13⅜" at 3720' is hereby confirmed.

Shell Oil Co. well No. "Reyes" 39. (Report No. T 1-17748.) Bailing test approved. 13⅜" casing cemented at 3718'. Hole swabbed to 1500' for test and stood 19 hr. Fluid level rose at rate of 11.4 bbl. in 24 hr. Fluid samples were: top, heavy gas-cut mud; 3725', heavy gas-cut mud with no evidence of free water.

Shell Oil Co. well No. "Reyes" 39. (Report No. T 1-17791.) Inspection of mudding operations. During ½ hr. circulation test mud fluid was lost from pit at rate of 1 bbl. per hr. Mudding operations are approved. Oral approval given to cement 10¾" at 4156' is hereby confirmed.

Shell Oil Co. well No. "Reyes" 39. (Report No. T 1-17911.) Bailing test approved. 10¾" casing cemented at 4151'. Hole swabbed to 1800' for

FOLD-OUT IS TOO LARGE TO BE FILMED

SUPREME COURT OF THE UNITED STATES.

No. 43.—October Term, 1931.

Bandini Petroleum Company, Commodore Petroleum Company, Wilshire Oil Company, et al.,
vs.
The Superior Court of the State of California in and for the County of Los Angeles and Honorable William Hazlett, as one of the Judges thereof.

Appeal from the District Court of Appeal of the State of California, Second Appellate District.

[November 23, 1931.]

Mr. Chief Justice Hughes delivered the opinion of the Court.

The appellants are producers of oil and gas from their respective wells in the Santa Fe Springs oil field in Los Angeles County, California. In September, 1929, the State, acting through its Director of Natural Resources, brought suit in the Superior Court of the State against the appellants and others, seeking to enjoin an alleged unreasonable waste of natural gas in that field. The authority for the suit was found in Sections 8b and 14b of what is called the Oil and Gas Conservation Act of California. Stats. Cal. 1915, ch. 718; 1917, ch. 759; 1919, ch. 536; 1921, ch. 912; 1929, ch. 535. Section 8b prohibits "the unreasonable waste of natural gas", and Section 14b authorizes suit by the Director of Natural Resources to enforce the prohibition.[1]

[1]These sections are as follows:

"Sec. 8b. The unreasonable waste of natural gas by the act, omission, sufferance or insistence of the lessor, lessee or operator of any land containing oil or gas, or both, whether before or after the removal of gasoline from such natural gas, is hereby declared to be opposed to the public interest and is hereby prohibited and declared to be unlawful. The blowing, release or escape of natural gas into the air shall be prima facie evidence of unreasonable waste." (Stats. Cal. 1929, ch. 535, p. 927.)

"Sec. 14b. Whenever it appears to the director of the department of natural resources that the owners, lessors, lessees, or operators of any well or wells producing oil and gas or oil or gas are causing or permitting an unreasonable waste of gas, he may institute, or have proceedings instituted, in the name of the people of the State of California, to enjoin such unreasonable waste of gas regardless of whether proceedings have or have not

The Superior Court granted a preliminary injunction after a hearing upon the pleadings, affidavits, oral testimony and documents submitted. The court recited in its order that there appeared to be an unreasonable waste of natural gas in the Santa Fe Springs oil field, and that an injunction was necessary in order "to preserve the subject matter of the action to abide the decree of the court at the conclusion of the trial." The court restricted the average daily production of "net formation gas" from "any lease or other property unit" to the amount shown for each operator in an accompanying schedule.[2] The court also directed each defen-

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been instituted under section 8 hereof, and regardless of whether an order has or has not been made therein. Such proceedings shall be instituted in the superior court for the county in which the well or wells from which the unreasonable waste of gas is occurring or any thereof are situated. The owners, lessors, lessees or operators causing or permitting an unreasonable waste of gas in the same oil or gas field, although their properties and interests may be separately owned and their unreasonable waste separate and distinct, may be made parties to said action. In such suits no restraining order shall be issued *ex parte*, but otherwise the procedure shall be governed by the provisions of chapter three, title seven, part two of the Code of Civil Procedure of the State of California and no temporary or permanent injunction issued in such proceedings shall be refused or dissolved or stayed pending appeal upon the giving of any bond or undertaking, or otherwise." (Stats. Cal. 1929, ch. 535, p. 930.)

[2]The injunction order sets forth "that the evidence available to the Court at this time shows that the unreasonable waste of natural gas in said field may be substantially reduced and that the equities of all parties may be fairly conserved by a preliminary injunction which will limit the waste of gas by restricting the production thereof to a quantity reasonably in excess of the present outlets for beneficial use above ground, require the extraction of gasoline from the gas produced in the field; that accordingly for the purposes of this order, the total gas outlets for all uses with a reasonable tolerance to take care of fluctuating demands and the necessary waste is taken at approximately two hundred eighty-five million (285,000,000) cubic feet of gas each day, and the estimated potential production of oil is taken at two hundred thirty-seven thousand five hundred seventy-six (237,576) barrels each day distributed among leases and other operating property units, as shown in the schedule hereafter set out; and that sufficient cause has been shown for the extraordinary relief of a preliminary injunction pending the trial of the action on the merits, and the entry of a final judgment herein;

"It Is Ordered and Decreed that the above named defendants . . . be and they hereby are restrained and enjoined . . . until the further order of this court as follows:

dant to file reports showing the daily production of gas and oil, and the order was without prejudice to the right of any of the parties to move on five days' notice for modification of the injunction. The court later modified the order in particulars not important here. Appellants state that the order curtailed their production of gas from 57,120,000 to 27,187,000 cubic feet a day.

Thereupon the appellants sought a writ of prohibition from the District Court of Appeal, Second Appellate District of the State, restraining the Superior Court and the respondent, William Hazlett, as one of its judges, from enforcing the injunction order. The jurisdiction of the Superior Court was attacked upon the ground of the invalidity of the statute invoked. The appellants contended, in substance, that the statute violated the due process clause of the Fourteenth Amendment in that it afforded no certain or definite standard as to what constituted "waste" or "unreasonable waste" and unlawfully delegated power to the Superior Court to legislate upon that subject; in that, upon the facts and as applied against the appellants, the statute prohibited them "from utilizing such amount of natural gas produced from their respective wells" as was "reasonably necessary to produce oil therefrom in quantities not exceeding a reasonable proportion to the amount of oil produced from the same well"; and in that the statute required appellants to curtail their production of oil and gas "for the purpose of conserving such natural gas for the benefit of the general public" without eminent domain proceedings and without just compensation, and was so arbitrary and oppressive that it

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"1. From blowing, releasing or permitting any natural gas to escape into the air from any well or wells in the Santa Fe Springs Oil Field before the removal of the gasoline from such natural gas.

"2. From operating any well producing natural gas in the Santa Fe Springs Oil Field except while exercising a high degree of care in the selection and adjustment of appliances and in the use thereof for the purpose of keeping each producing well in its 'optimum gas-oil ratio'—the term 'optimum gas-oil ratio' being defined as the smallest number of cubic feet of gas which can be produced with each barrel of oil from the same well at the same time.

"3. From producing more net formation gas on the average day of each seven (7) day period from any lease or other property unit than is set forth in the 'Allowed Gas Production' column" than that shown for each operator in the accompanying schedule.

was in excess of the power of the State. By reference to their pleadings in the injunction suit, the appellants also assailed, under the due process clause, the provision of the statute as to what should constitute *prima facie* evidence of unreasonable waste, and the appellants further insisted that the statute as enforced against them impaired the obligation of their lease contracts in violation of the contract clause of the Federal Constitution and that they were denied the equal protection of the laws as guaranteed by the Fourteenth Amendment.

The respondents (appellees here) demurred to the petition, and the District Court of Appeal, entertaining and overruling the contentions of the appellants under the due process clause, denied the writ of prohibition. 63 Cal. App. Dec. 1175, 293 Pac. 899. The appellants then applied for a hearing in the Supreme Court of the State and, this having been denied, they seek in this Court a review of the judgment of the District Court of Appeal.

This Court has jurisdiction. The proceeding for a writ of prohibition is a distinct suit and the judgment finally disposing of it is a final judgment within the meaning of section 237 (a) of the Judicial Code. U. S. C., Tit. 28, sec. 344. *Weston* v. *Charleston*, 2 Pet. 449, 464; *Mt. Vernon Cotton Company* v. *Alabama Power Company*, 240 U. S. 30, 31; *State of Missouri ex rel. St. Louis B. & M. Rwy. Co.* v. *Taylor*, 266 U. S. 200, 206; *Michigan Central R. R. Co.* v. *Mix*, 278 U. S. 492, 494. That judgment, however, merely dealt with the jurisdiction of the Superior Court of the suit for injunction, and the only question before us is whether the District Court of Appeal erred in deciding the Federal questions as to the validity of the statute upon which that jurisdiction was based. Moreover, with all questions of fact, or with questions of law which would appropriately be raised upon the facts adduced in the trial of the case in the Superior Court, as a court competent to entertain the suit, we are not concerned on this appeal. The appellants annexed to their petition in the prohibition proceeding, and made a part of it, the pleadings in the injunction suit and the affidavits presented upon the hearing of the application for preliminary injunction. But they could not in that manner, or by their characterization of the evidence thus adduced, or by pleading the conclusions derived therefrom, substitute the District Court of Ap-

peal for the Superior Court in the determination of the facts, or of the law as addressed to the facts, which should properly be considered by the latter tribunal. It appears that in California, in accordance with the general conception of the province of the writ, prohibition is for the purpose of arresting the proceedings of any tribunal exercising judicial functions when such proceedings are without, or in excess of, jurisdiction. Cal. Code of Civ. Pro., secs. 1102, 1103; *Jacobsen* v. *Superior Court,* 192 Cal. 319; 219 Pac. 986. See, also, *Baar* v. *Smith,* 201 Cal. 87, 101; 255 Pac. 827, 833. The writ of prohibition is not available as a substitute for an appeal from a court having jurisdiction. As was said by the Supreme Court of California, in *Truck Owners & Shippers, Inc.,* v. *Superior Court,* 194 Cal. 146, 155; 228 Pac. 19, 22, 23: "If the superior court has jurisdiction to entertain the action it has the power to define the right sought to be protected. . . . If the judgment of the superior court be incorrect, it may be reversed on appeal but not on prohibition."

After the decision of the District Court of Appeal, and before the denial by the Supreme Court of the State of a hearing in the instant case, the latter court passed upon the constitutional validity of the statute in question. That decision was made upon an application for a writ of *supersedeas* pending an appeal by certain co-defendants of the appellants here (who were not parties to the appeal) from the above mentioned injunction order. *People ex rel. Stevenot, Director of Natural Resources* v. *Associated Oil Company, et al.,* 80 Cal. Dec. 607; 294 Pac. 717. The Supreme Court found no reason to interfere with the action of the Superior Court, and, later, the Supreme Court, on that appeal, affirmed the injunction order holding that under the statute the Superior Court had the power to determine what wastage of gas in the production of oil was unreasonable. *id.* 81 Cal. Dec. 468, 471; 297 Pac. 536, 537. The District Court of Appeal, in the instant case, had expressed the same opinion and accordingly decided that it could not interefere by writ of prohibition. 63 Cal. App. Dec. at p. 1186; 293 Pac. at p. 907.

It follows that, in considering and deciding Federal questions in the prohibition proceeding, the District Court of Appeal must be regarded, as its opinion imports, as having determined merely

that the statute was valid upon its face so that the Superior Court had jurisdiction to entertain the injunction suit. It is that determination alone that we can now consider.

The District Court of Appeal overruled the contention that the statute was so uncertain and devoid of any definition of a standard of conduct as to be inconsistent with due process. The Supreme Court of the State, reaching the same conclusion (in the opinion above cited, 80 Cal. Dec. at pp. 614, 615; 294 Pac. at p. 724) described the general condition in which oil and gas were found in California and the standard which the court considered to be established by the statute. After observing that courts were entitled to take judicial notice of the condition and development of the petroleum industry, and of matters of science and common knowledge, and referring to scientific reports, the Supreme Court said:

"For present purposes it need only be noted that oil in this state is found under layers of rock in a sand or sandstone formation termed a lentille or 'lentil', under pressure caused by the presence of natural gas within the formation. The layers of rock thus form a gas-tight dome or cover for the oil reserve. The oil adheres in the interstices between the sand particles. The natural gas may be in a free state at the top of the dome, but is also in solution with the oil, thus increasing the fluidity of the oil and the ease with which the oil is lifted with the gas in solution when the pressure on the gas is released by drilling into the oil 'sand.' It is estimated that only from ten to twenty-five per cent. of the total amount of oil deposited in a reservoir is ultimately recovered, depending on the natural characteristics of the reservoir and the methods employed in utilizing the lifting power of the gas. The importance of gas in the oil-producing industry has, therefore, become a question of great concern to the industry itself and to government, to the end that its function may be fully utilized without waste. It fairly appears on this application that, depending on its location in the oil reservoir, the extent of the oil 'sand', the degree of pressure within the formation, the amount of oil in the 'sand', the amount of gas in solution with the oil, the porosity of the 'sand' and other considerations, each oil and gas well has a best mean gas and oil ratio in the utilization of the lifting power of the gas and the production of the greatest quantity of oil in proportion to the amount of gas so utilized, and which may be computed as to each individual well to a reasonable degree of certainty and be regulated accordingly."

In view of these circumstances, the Supreme Court concluded that it might be said that there was an "unreasonable waste" of gas where it "has been allowed to come to the surface without its lifting power having been utilized to produce the greatest quantity of oil in proportion". It was such a waste of gas, the court said, that the legislature of California intended to prohibit. In support of this conclusion the court referred to the provisions of section 8d of the statute.[3] These provisions showed, in the opinion of the court, that the legislature had "plainly adopted the standard so expressed", that is, "that gas may not be produced, under existing conditions where the production thereof so greatly exceeds the market demand therefor, in quantities exceeding a reasonable proportion to the amount of oil produced." And, in explanation of its reasons for considering such a standard sufficiently definite, the court said that "because of the many and varying conditions peculiar to each reservoir and to each well, which will bear upon a determination of what is a reasonable proportion of gas to the amount of oil produced, it may be said that it would be impossible for the legislature to frame a measure based on ratios or percentages or definite proportions which would operate without discrimination, and that what is a reasonable proportion of gas to the amount of oil produced from each well or reservoir is a matter which may be ascertained to a fair degree of certainty in each individual case."

The statute is to be read with the construction placed upon it by the state court. *Lindsley* v. *Natural Carbonic Gas Company*, 220

[3]Section 8d relates to the procedure upon complaint of undue waste, and the portion quoted by the Supreme Court of the State is as follows: "If it shall appear that gas is being produced from any oil well or wells in quantities exceeding a reasonable proportion to the amount of oil produced from the same well or wells, even though it is shown that such excess gas is being used in the generation of light, heat, power or other industrial purpose and that there is sufficient other gas available for such uses from other wells in the same or other fields in which the gas produced is not in excess of the amount which bears a reasonable proportion to the amount of oil produced from such other wells and that there are adequate gas-pipe-line connections between such other wells and the place of utilization of such gas the state oil and gas supervisor shall hold that such excess production of gas is unreasonable waste thereof if such holding will not cause an unreasonable waste of gas in any other field."

U. S. 61, 73. And so read, we find no ground for concluding that the statute should be regarded as invalid upon its face, merely by reason of uncertainty, so as to deprive the Superior Court of jurisdiction to consider the relevant questions of fact and to determine with respect to a particular field whether or not there has been the unreasonable waste of gas which the statute condemns. *Nash* v. *United States*, 229 U. S. 373, 377; *Müller* v. *Strahl*, 239 U. S. 426, 434; *Omaechevarria* v. *Idaho*, 246 U. S. 343, 348; *Hygrade Provision Company* v. *Sherman*, 266 U. S. 497, 502.

The appellants make the further contention that the statute is invalid because of the provision of section 8b (*supra*, p. —) that "the blowing, release or escape of natural gas into the air shall be *prima facie* evidence of unreasonable waste." The State, in the exercise of its general power to prescribe rules of evidence, may provide that proof of a particular fact, or of several facts taken collectively, shall be *prima facie* evidence of another fact when there is some rational connection between the fact proved and the ultimate fact presumed. The legislative presumption is invalid when it is entirely arbitrary, or creates an invidious discrimination, or operates to deprive a party of a reasonable opportunity to present the pertinent facts in his defense. *Mobile, etc., Railroad Company* v. *Turnipseed*, 219 U. S. 35, 43; *Bailey* v. *Alabama*, 219 U. S. 218, 238; *Lindsley* v. *Natural Carbonic Gas Company, supra*, at pp. 81, 82; *Manley* v. *Georgia*, 279 U. S. 1, 5, 6; *Western & Atlantic* v. *Henderson*, 279 U. S. 639, 642. In the present case there is a manifest connection between the fact proved and the fact presumed, and under the construction placed upon the statute by the state court there appears to be no deprivation of a full opportunity to present all the facts relating to operations within the field.

The question remains whether the statutory scheme of regulation, with the standard which it sets up under the construction of the state court, is on its face beyond the power of the State. The District Court of Appeal, in the instant case, approached this question by considering the correlative rights, under the law of California, of surface owners in the same field. The court concluded that under the law of California "on account of the self propelling or migratory character of natural gas, as well as oil", the owner of the surface did not have an absolute title to the gas and oil be-

neath, and could acquire such a title only when he had reduced these substances to possession. As justifying this opinion, the court cited the case of *Acme Oil Company* v. *Williams* (140 Cal. 681; 74 Pac. 296) where the Supreme Court of the State had said, with respect to oil, that it is "of a fluctuating, uncertain, fugitive nature, lies at unknown depths, and the quantity, extent and trend of its flow are uncertain. It requires but a small surface area, in what is known as an oil district, upon which to commence operations for its discovery. But when a well is developed the oil may be tributary to it for a long distance through the strata which hold it. This flow is not inexhaustible, no certain control over it can be exercised, and its actual possession can only be obtained, as against others in the same field, engaged in the same enterprise, by diligent and continuous pumping. It is the property of anybody who can acquire the surface right to bore for it, and when the flow is penetrated, he who operates his well most diligently obtains the greatest benefit, and this advantage is increased in proportion as his neighbor similarly situated neglects his opportunity." And the Supreme Court of the State, in its decision dealing with the statute in question, quoted this language and held that "the same rule would apply to natural gas". 80 Cal. at p. 612; 294 Pac. at p. 722.

It was with that understanding of the law of the State that the District Court of Appeal considered the statute, taken as a whole, as one regulating and adjusting the co-existing rights of the surface owners in the same field and accordingly sustained the statute as a valid exercise of state power against the contentions under the due process clause. The court said: "It is the coexistence of these rights which authorizes the State to make use of its legislative power. When the rights of one impinge upon the rights of others the State may interpose for the purpose of adjusting and regulating the enjoyment of those rights". The District Court of Appeal apparently thought it doubtful whether the State might restrict or regulate the production of oil or gas "on the theory of the public's interest in their natural resources" but deemed it unnecessary to decide that question in the present case. That court explicitly refused to accept the view that the statute "does not proceed upon the theory of correlative rights, but only upon the